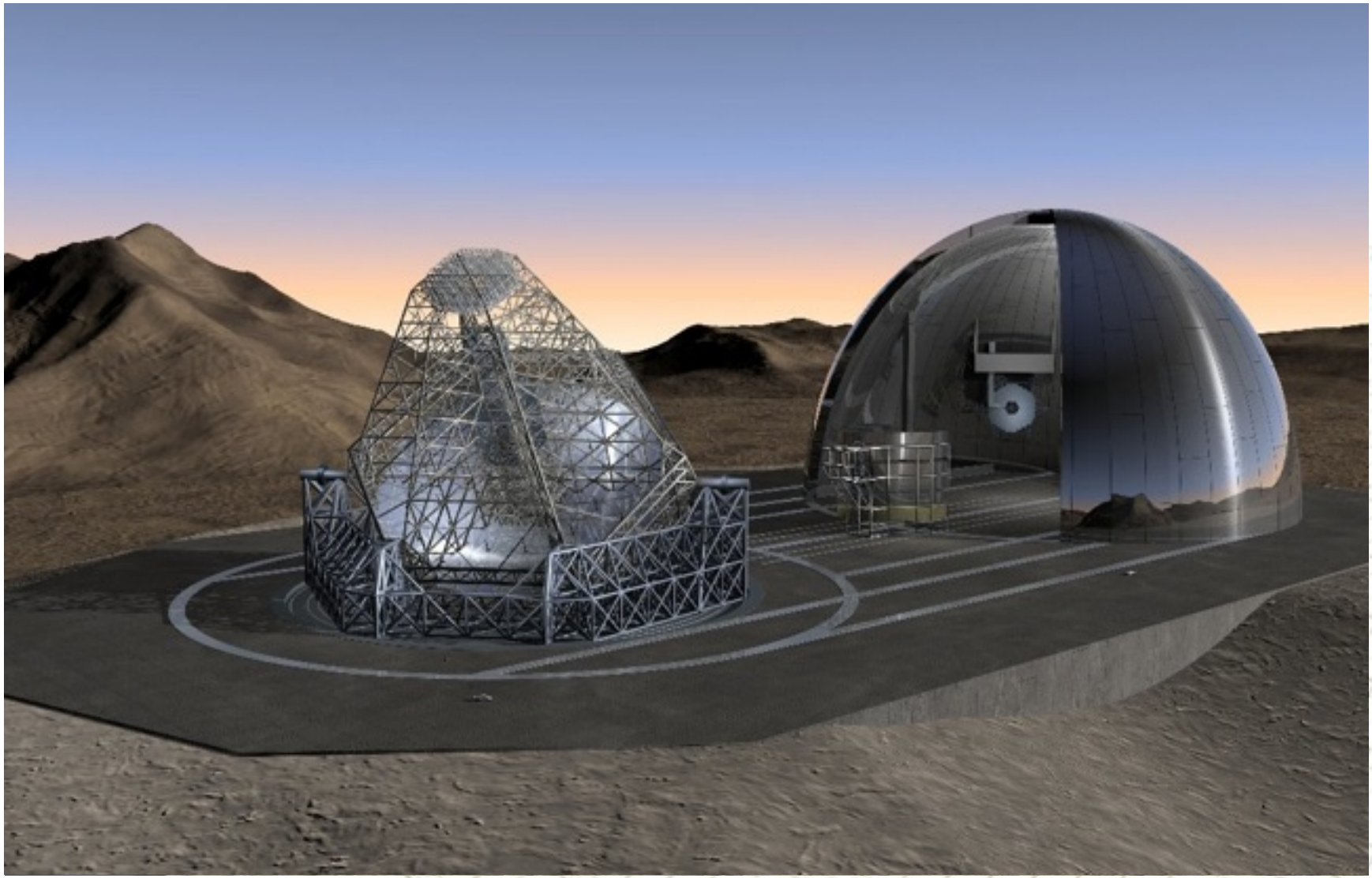
Science & technology of the E-ELT

Roberto Gilmozzi, ESO
Deputy Director of Programmes
Rome, 18 Feb 2014

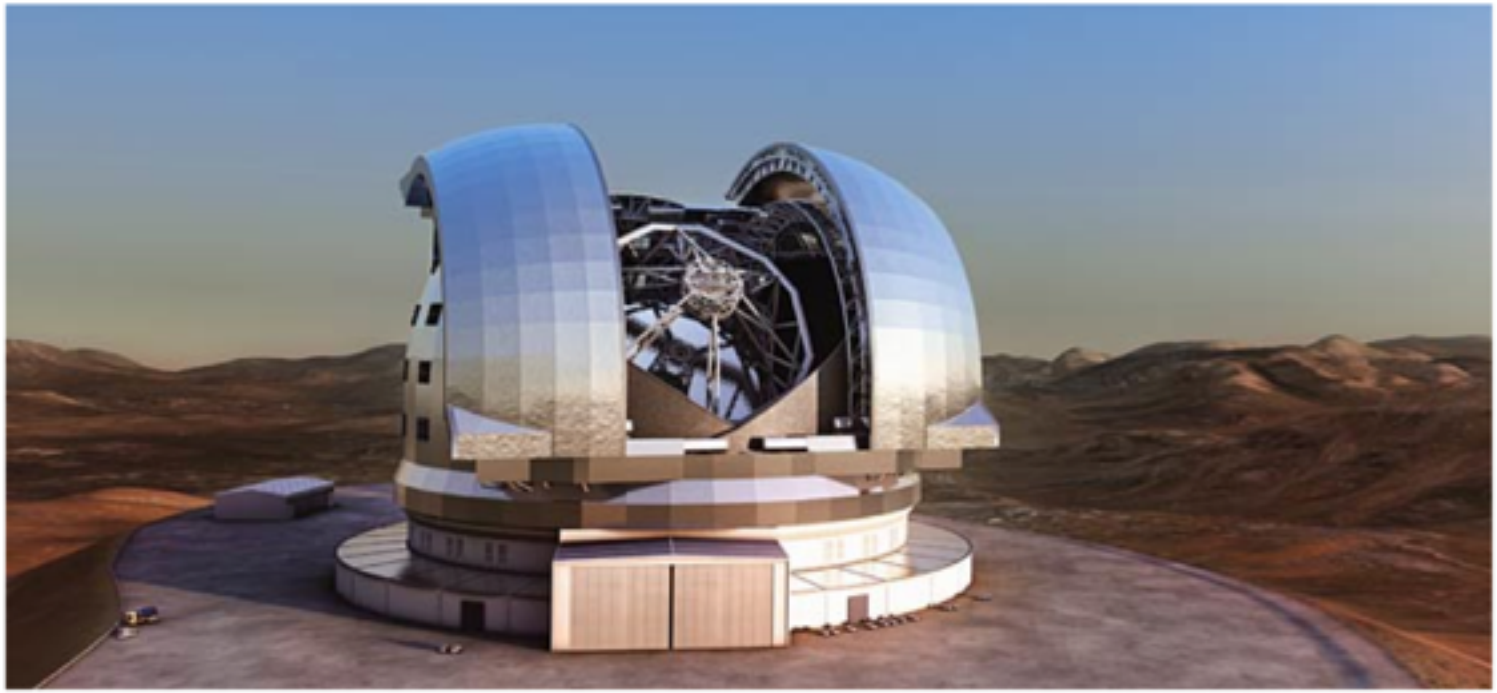
History: 1998-2012



Becoming reality…

ESO To Build World's Biggest Eye On The Sky

11 June 2012



Click to Enlarge

ESO is to build the largest optical/infrared telescope in the world. At its meeting in Garching today, the ESO Council approved the European Extremely Large Telescope (E-ELT) Programme, pending confirmation of four so-called ad referendum [1] votes. The E-ELT will start operations early in the next decade.

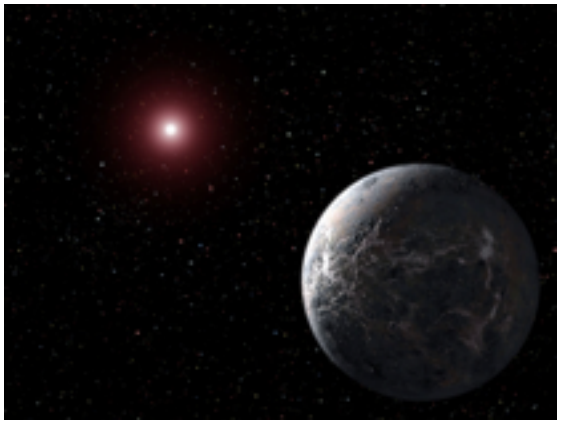
ESO's governing body, the Council, met today, at the ESO Headquarters in Garching, Germany. The main topic on the agenda was the start of the European Extremely Large Telescope (E-ELT) Programme — the world's biggest eye on the sky. The E-ELT will be a 39.3-metre segmented-mirror telescope sited on Cerro Armazones in northern Chile, close to ESO's Paranal Observatory.

The European ELT

- A 40m class adaptive telescope based on a 5-mirror design
- Completed Phase B (detailed design): 2007-2010
  - Construction Review (Sep 2010, passed)
- Completed Δ Phase B
  - Goal: optimize solutions, reduce cost (1.25 B€) and risks
  - Two Cost Reviews (Sep, Oct 2011, both passed)
- Schedule:
  - Start of construction: 2014
  - First light: 2023
- Cost
  - Telescope + 1st gen instruments: 1083 million Euros
  - Operations (incl new instruments, overheads): ~ 50 M€/year
- Status
  - **Programme approved (Dec 2012), 2/3 of cost committed**
  - Testing, prototypes, **M4 contract underway**, **road & site prep contract signed**, CfT documents for main items in prep
  - Construction to start when 90% of funds pledged

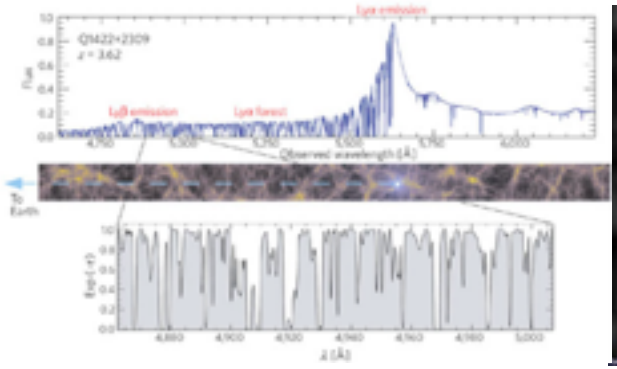
The driver

- **Planets in other stellar systems**
  - Imaging and spectroscopy
  - *The quest for Earth-like exo-planets*

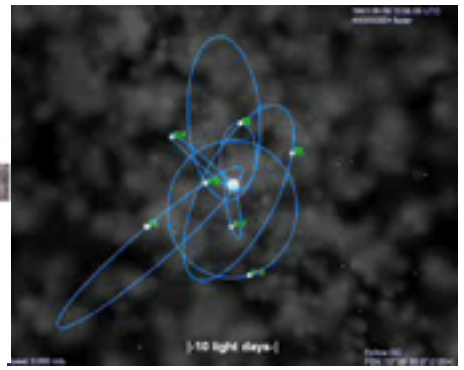


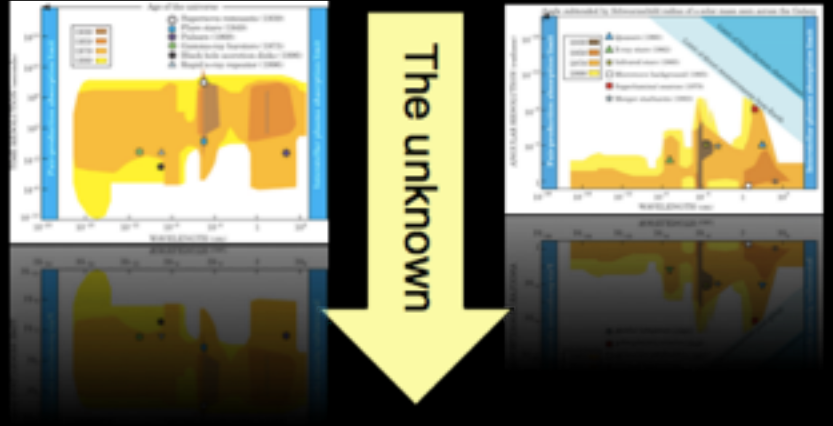
- **Stellar populations**
  - In galaxies inaccessible today (e.g. ellipticals in Virgo cluster)
  - Across the whole history (i.e. extent) of the Universe

- **Cosmology**
  - The first stars/galaxies
  - Direct measure of deceleration
  - Evolution of cosmic parameters
  - Tests of GR around black holes

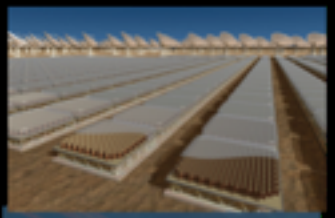


- **The unknown**
  - Open new parameter space





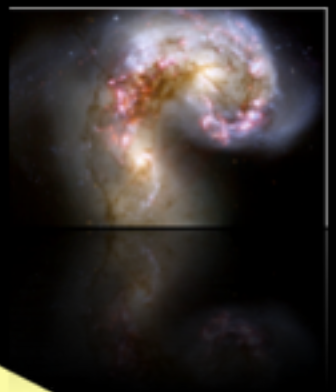
The unknown

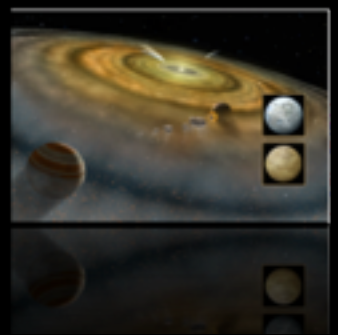


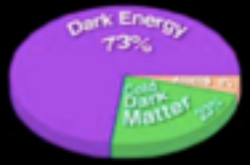
ELTs Science Case

Synergies

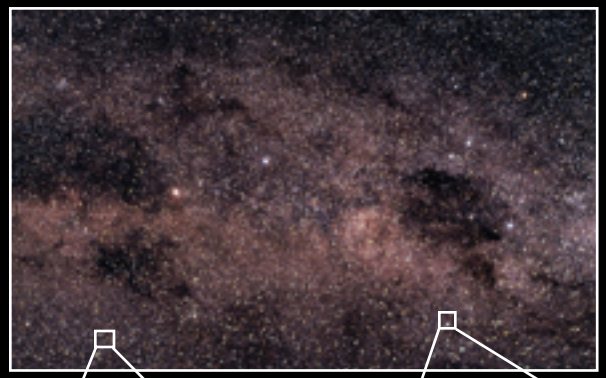
Today's science





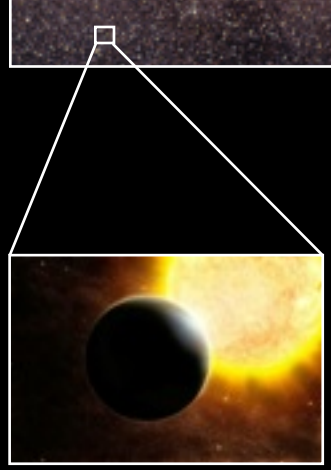


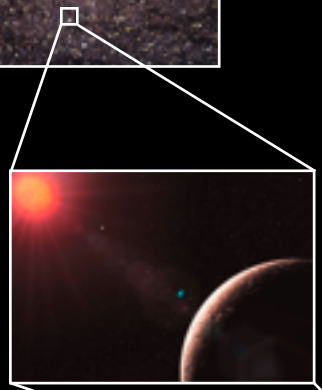
One top goal of the E-ELT is to find and to characterise exo-planets...

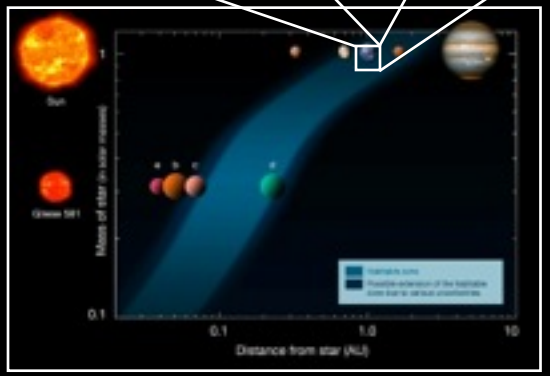


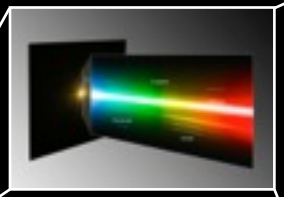
... it is the first telescope ever that can explore Earth-twins...

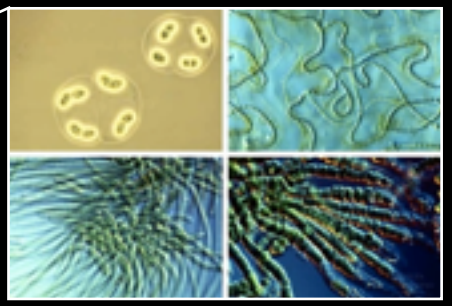
... with ultimately the chance to find life beyond the Solar system.



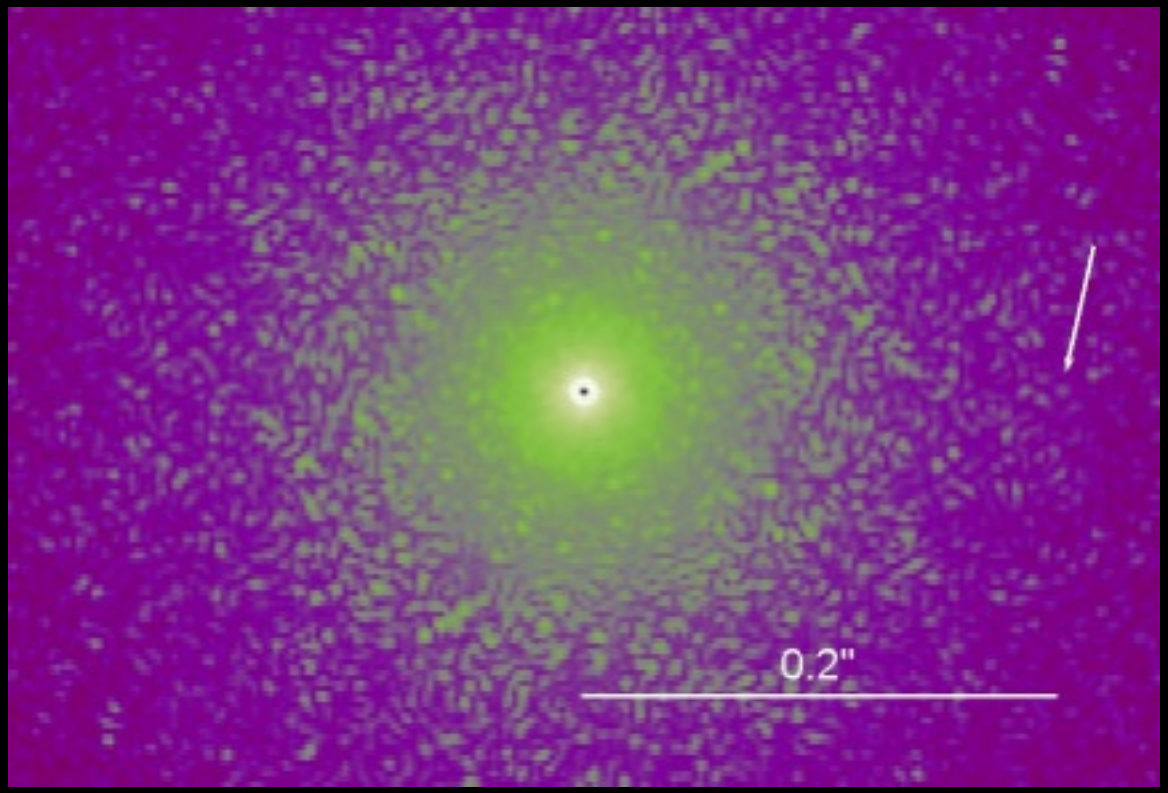








Integral Field Spectroscopy simulations



Courtesy Szymon Gładysz

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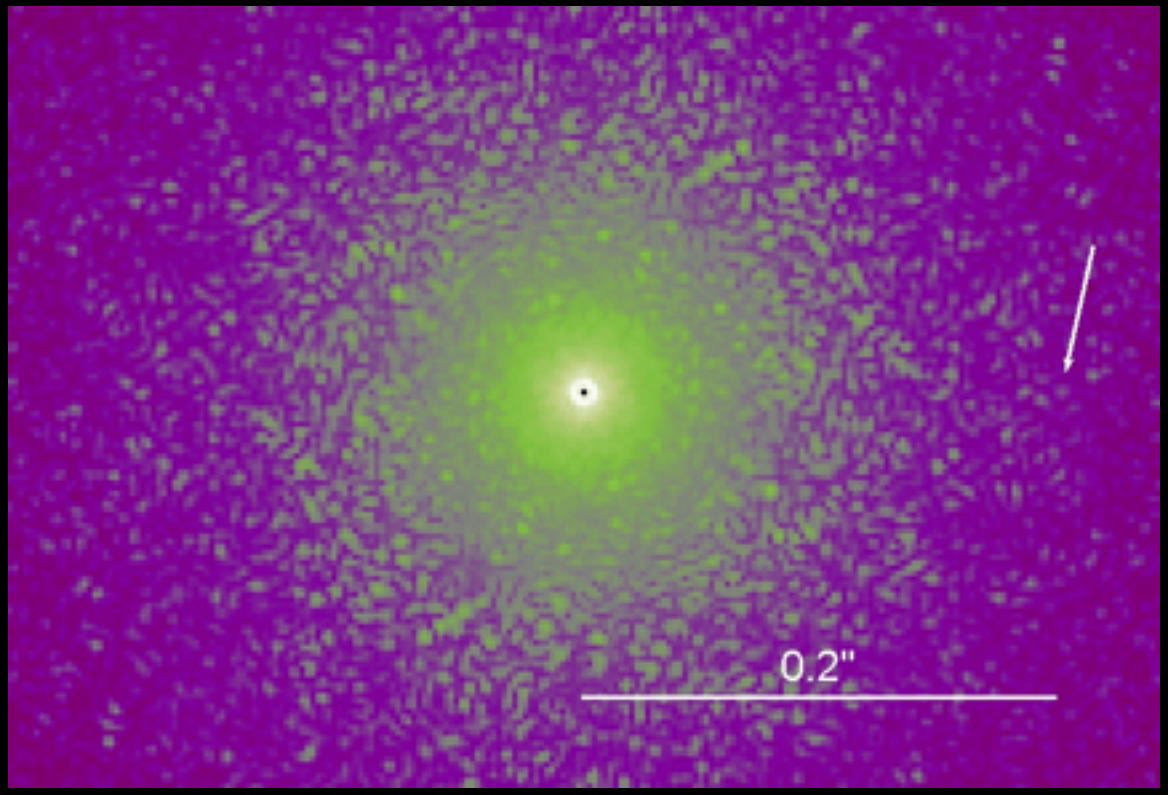
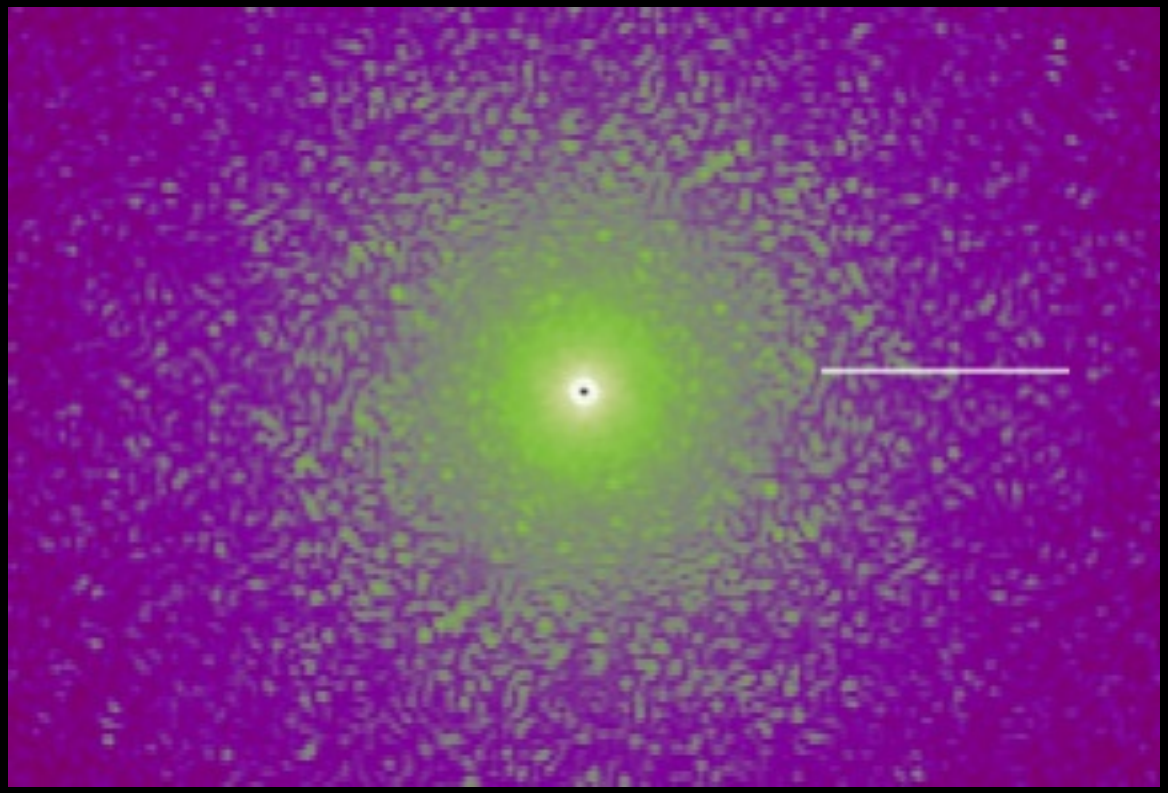


Courtesy Szymon Gładysz

Post-processing

spectral deconvolution



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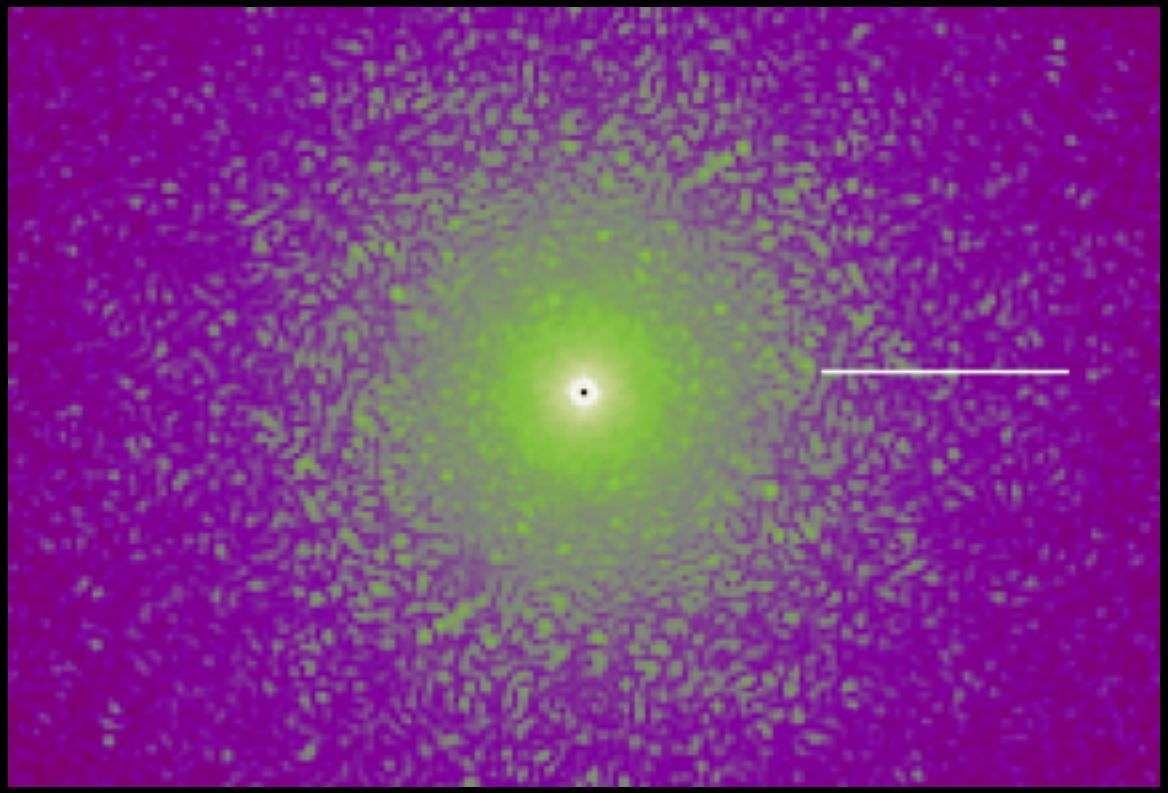

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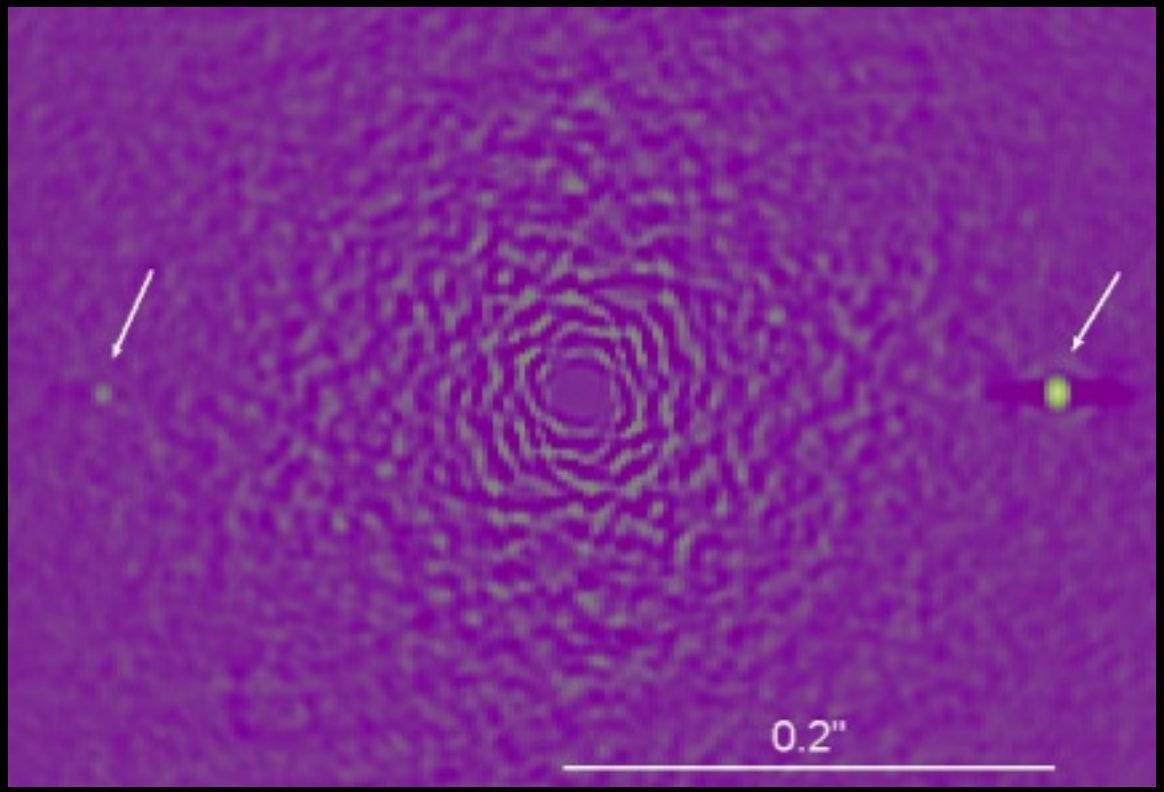
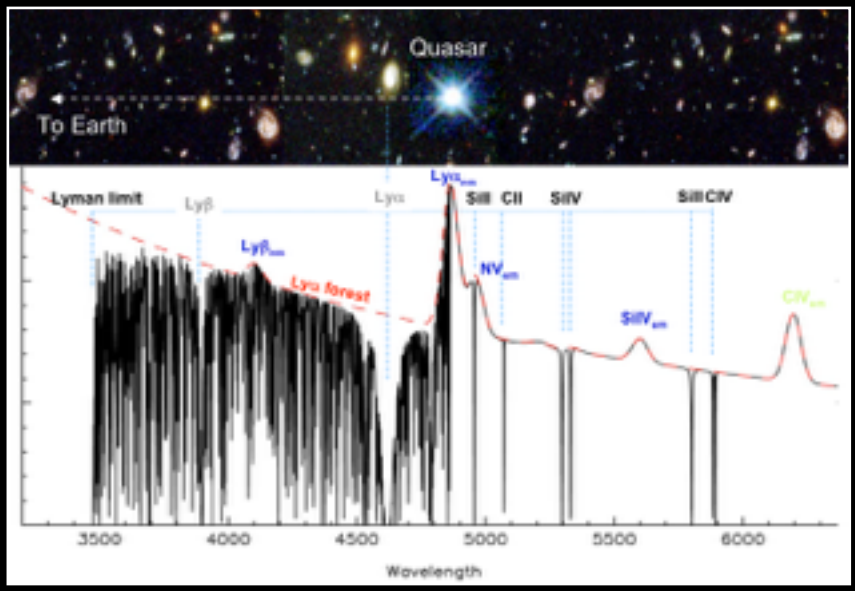
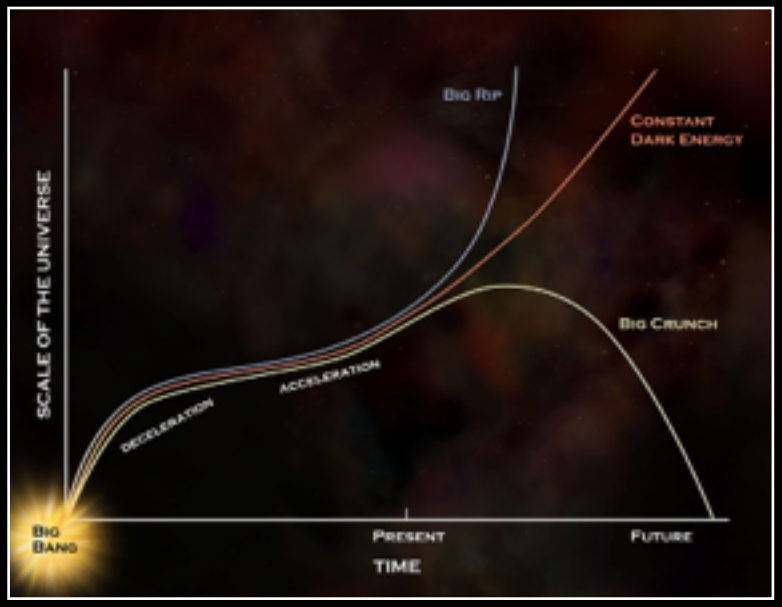


Courtesy Szymon Gładysz

Another top goal of the E-ELT is fundamental physics…

…the E-ELT will be able to test whether today's physics was valid 10 billion years ago…





… and it will be able to trace the expansion history of the universe, providing clues about dark energy.

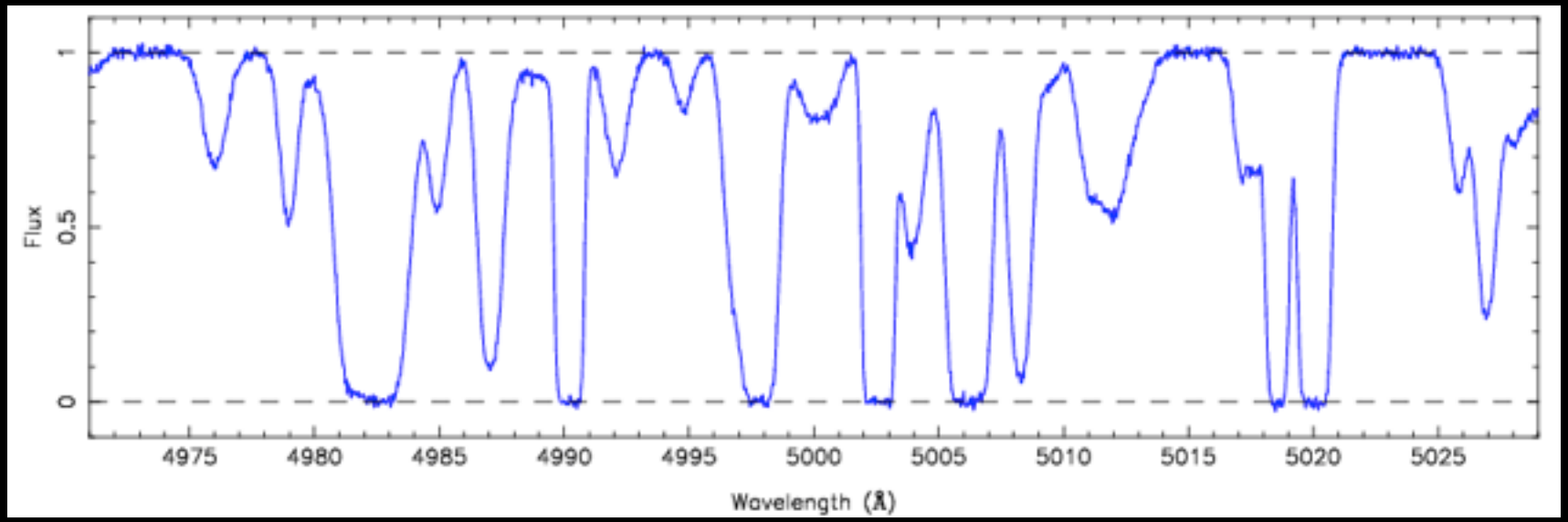
Cosmic Dynamics Experiment

$$\dot{z} = \frac{dz}{dt} = (1+z)\,H_0 - H(t_e)$$

Measuring the redshift drift requires:

- Many photons, high resolution, extremely stable spectrograph
- ~20 yr long spectroscopic monitoring campaign

Best place to observe the redshift drift: the Lyman-α forest.



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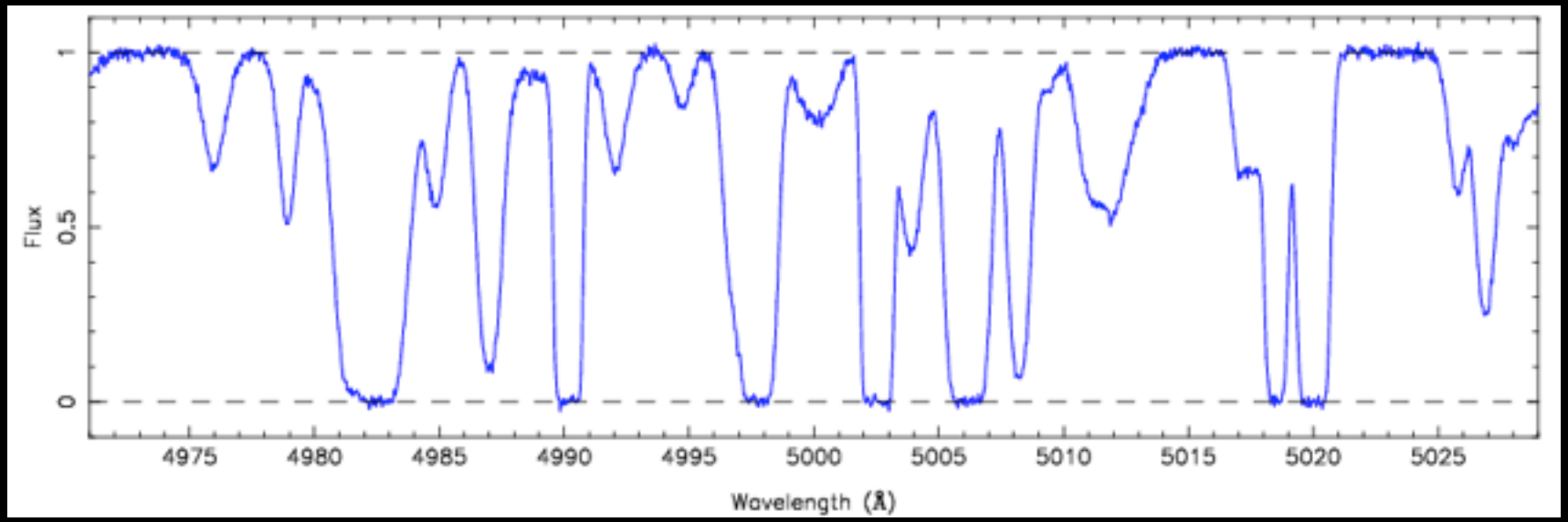

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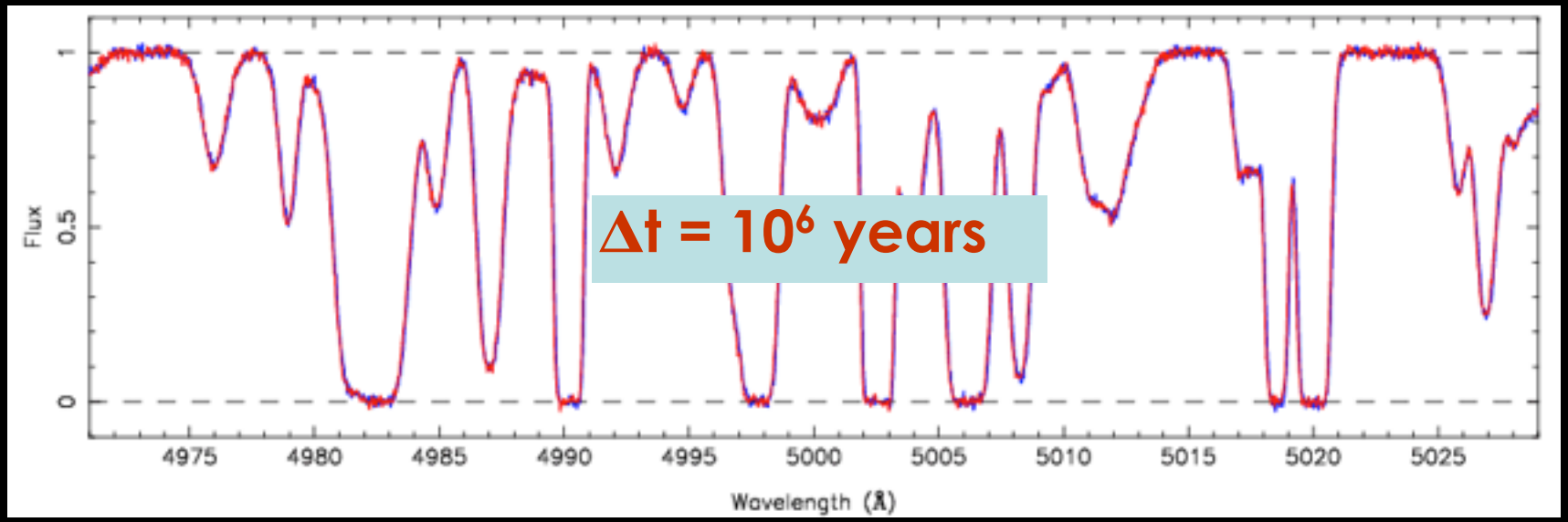
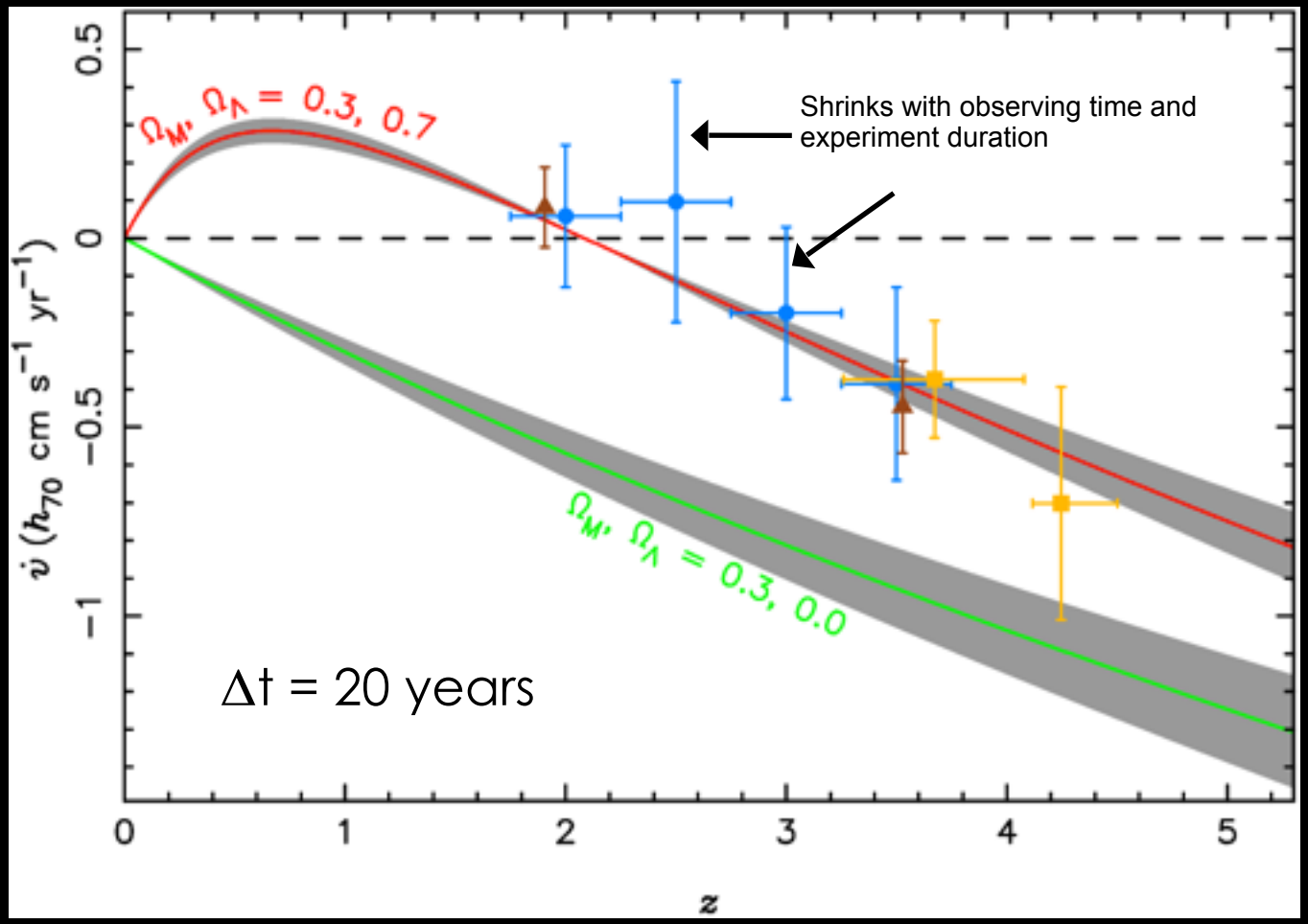


Cosmic Dynamics Experiment

Simulations:

4000 hours over 20 years will deliver any *one* of these sets of points.

Different sets correspond to different target selection strategies.



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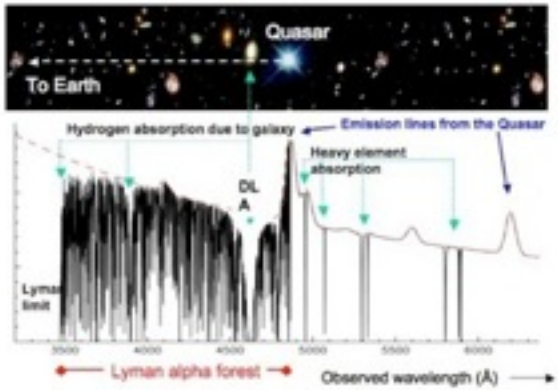
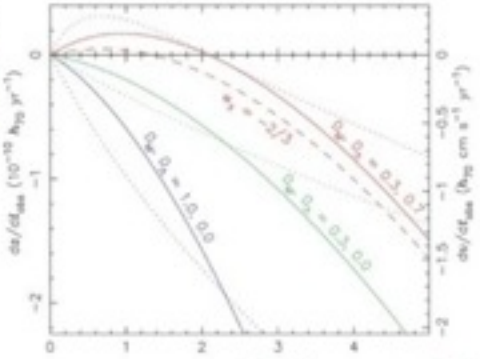
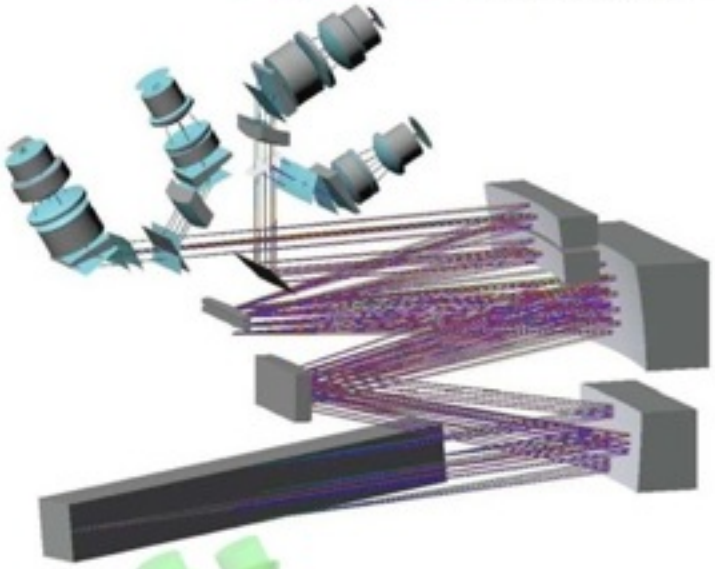
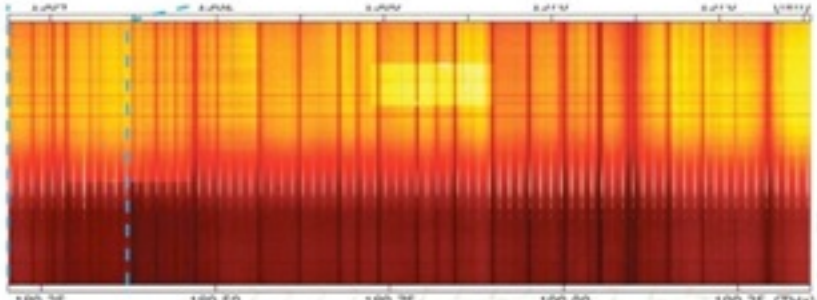
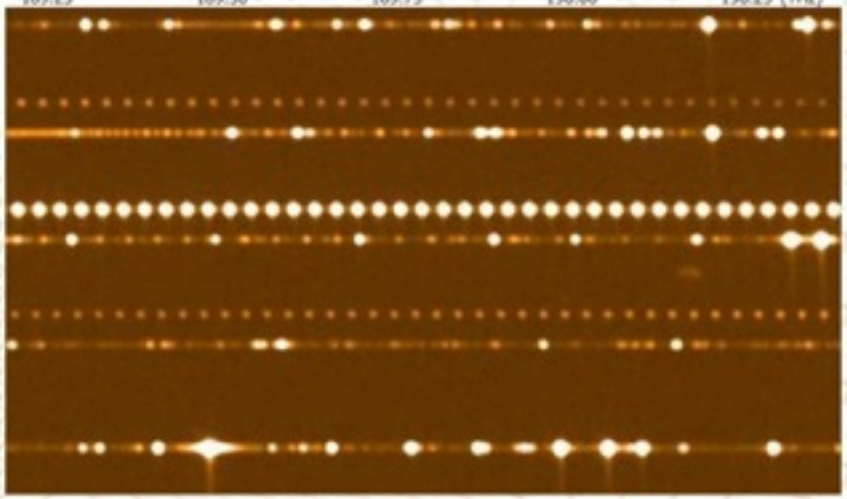
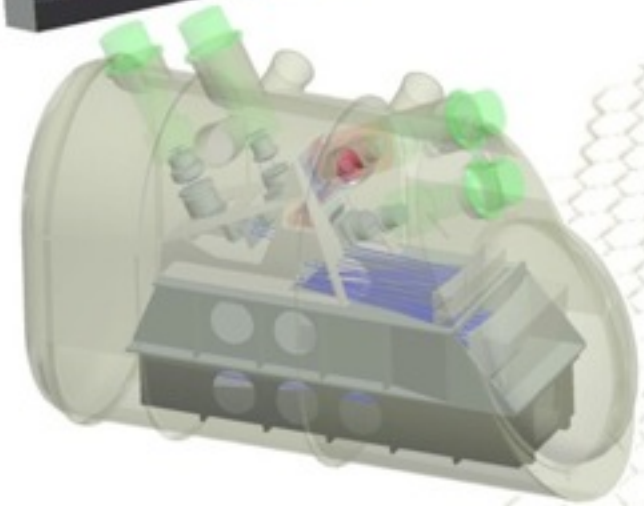




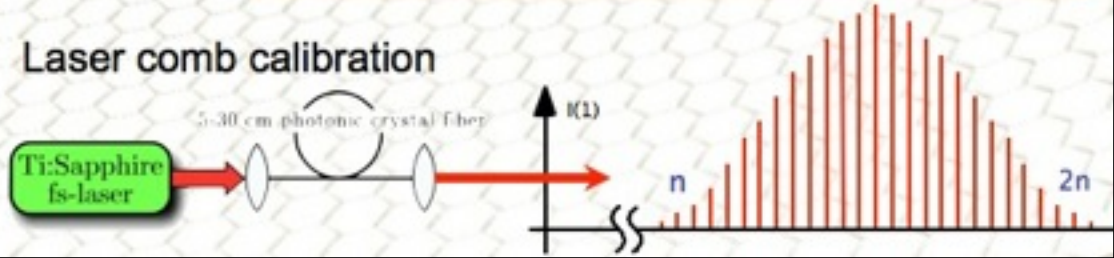








Laser comb calibration

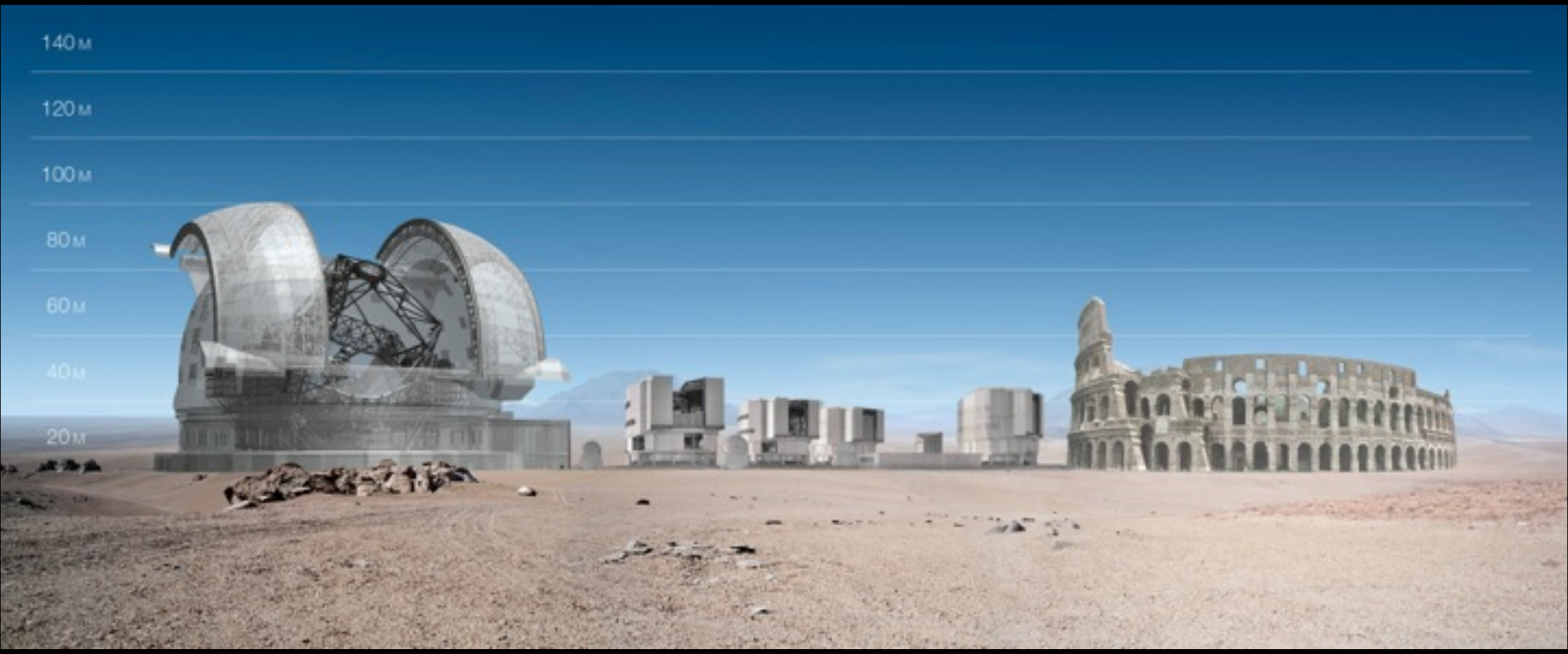


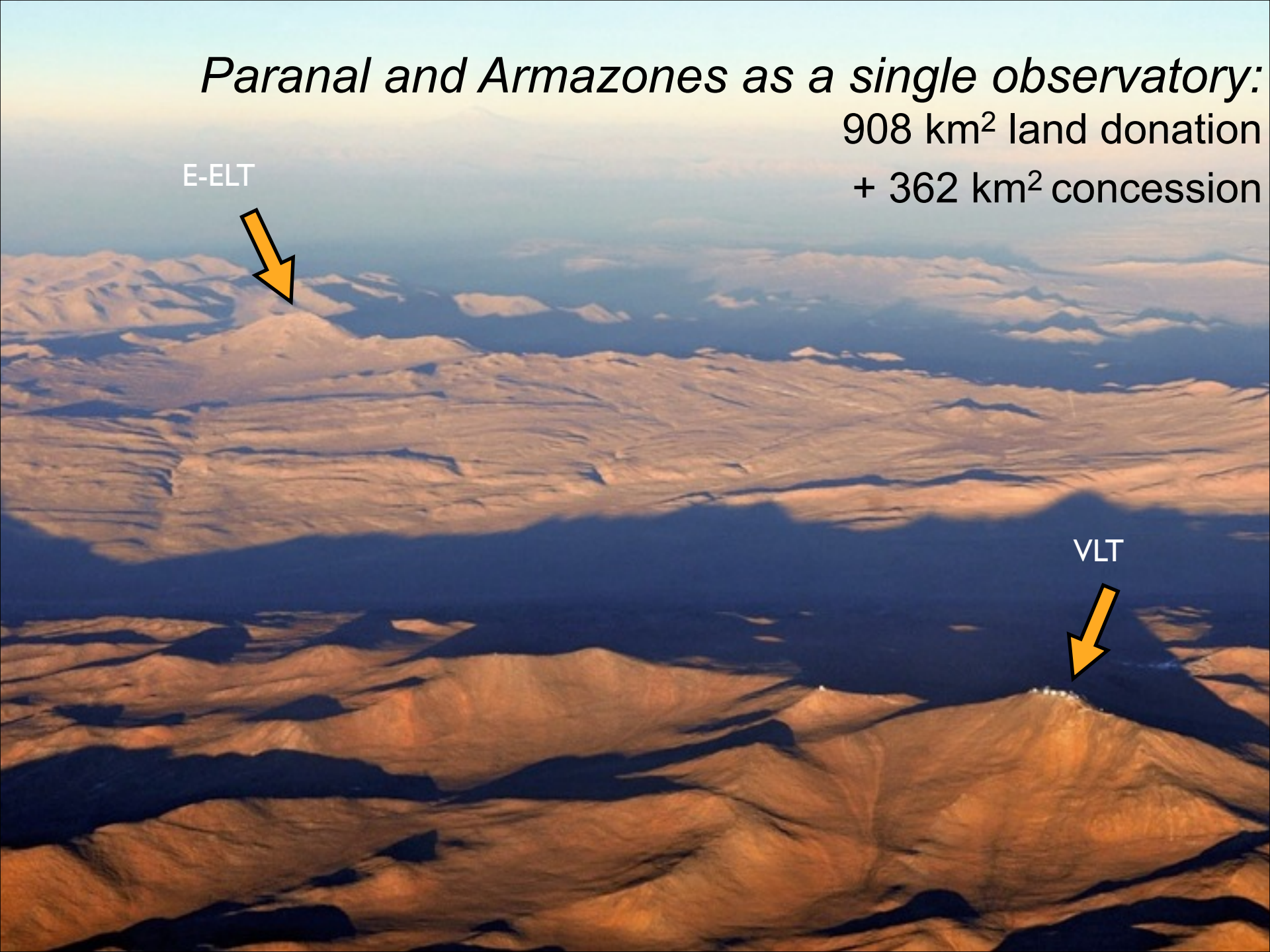
Science → Requirements

- **Diameter: ≥39m (area ≥ 1000 m^2)**
  - Alt-Az, F/17.5, fully steerable (0-360,0-90). Operational ZD: 0-70
- **Adaptive telescope**
  - GLAO correction (≥ 5 arcmin, 90% sky, 80% time)
    - better than 2x FWHM improvement for median seeing conditions
  - Post-focal: SCAO, MCAO, LTAO, ExAO, MOAO, ...
- **Science field of view:**
  - 10 arcmin unvignetted. Diffraction limited by design
  - 5 arcmin unobscured by guide probes
- **Wavelength range: 0.3 − 24 μm**
- **Transmission @Nasmyth:**

  >50% at >0.35 μm, >60 % at >0.4 μm, >70% at 0.7 μm, >80% at > 1 μm
- **Focal stations**
  - Two Nasmyth (multiple instruments)
  - At least one Coudé (F/60)
  - Fixed instrumentation (fast switching: < 10 min same focus, < 20 otherwise)

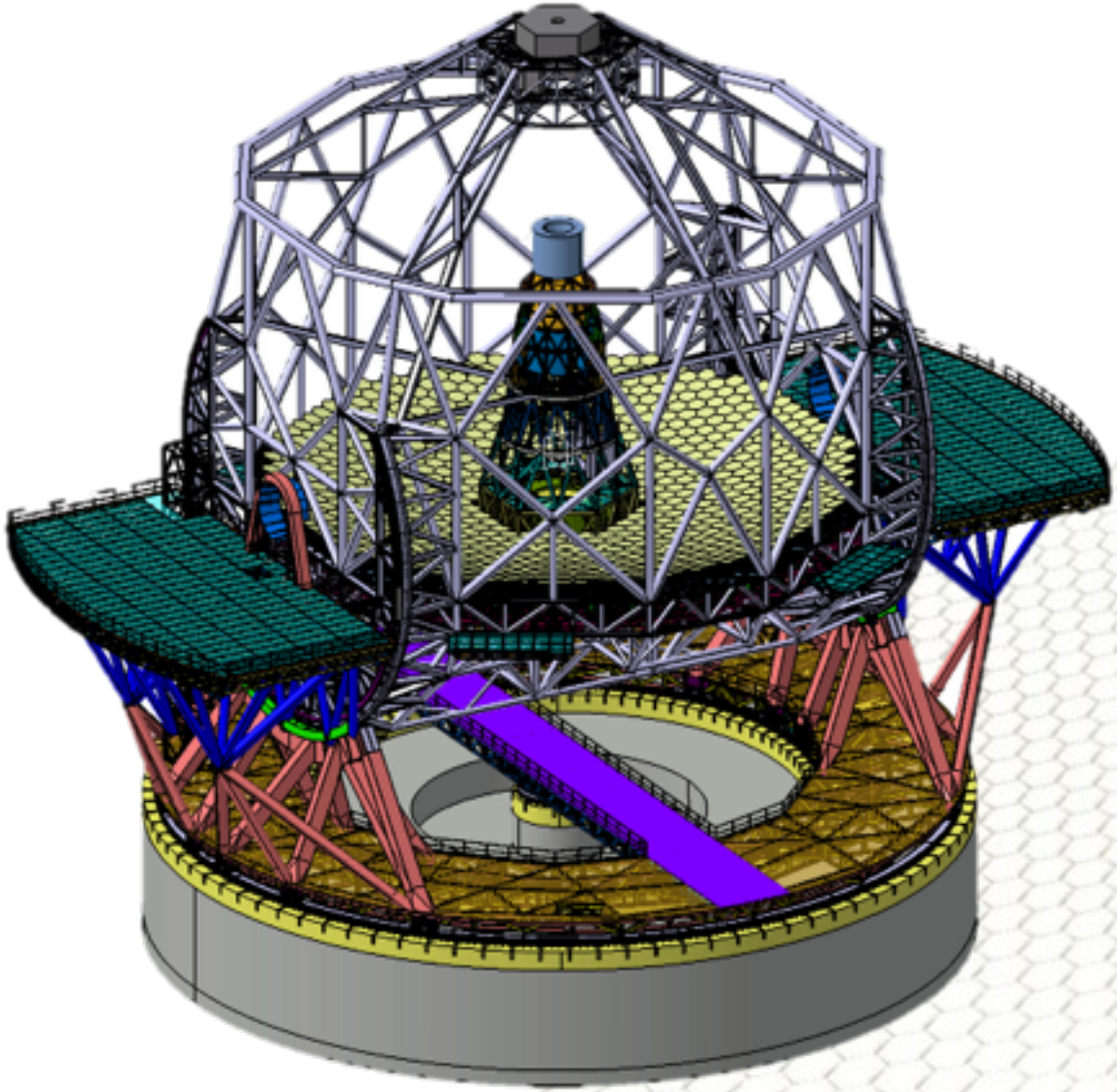
To put it in perspective…



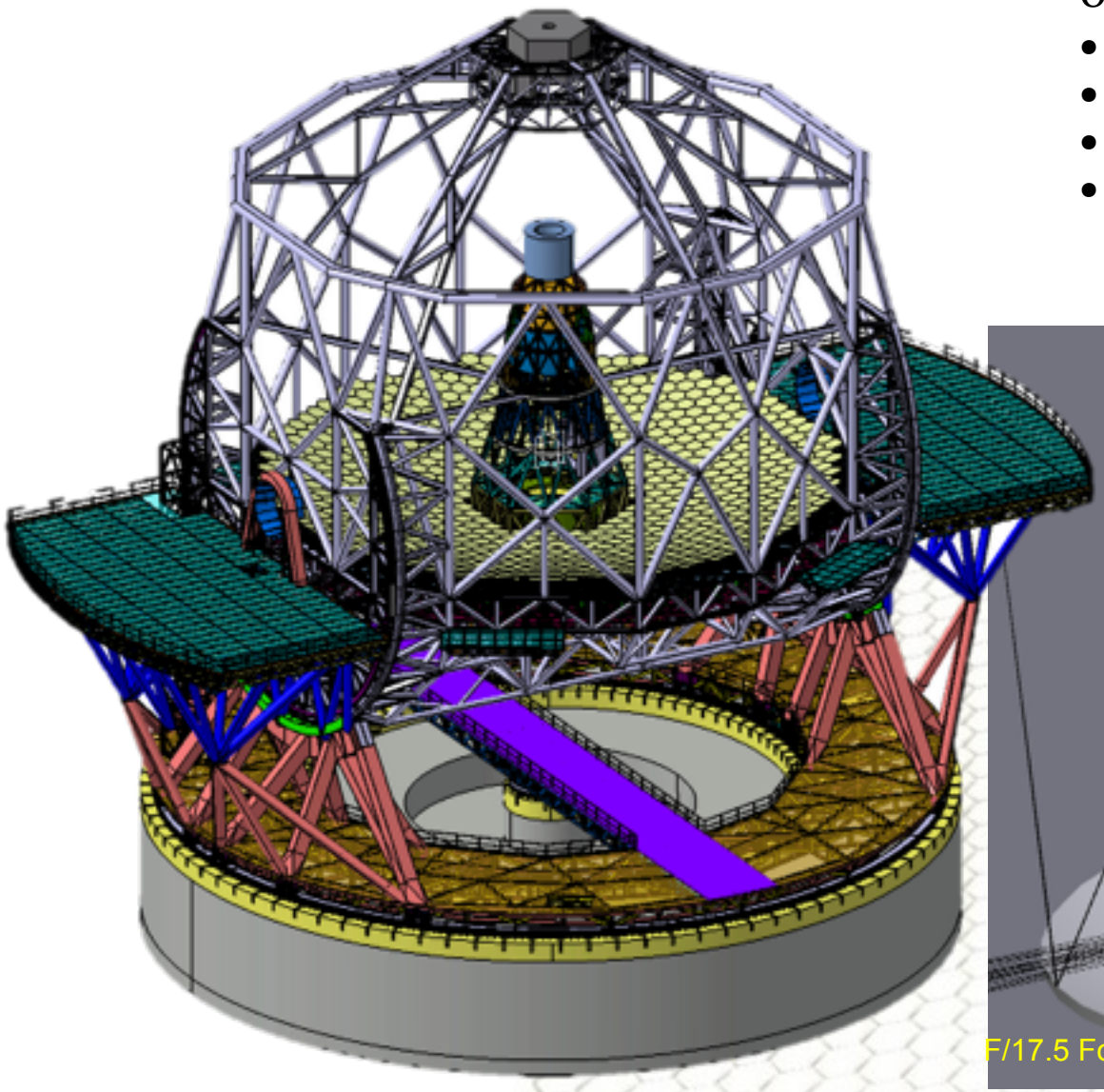

Paranal and Armazones as a single observatory:
908 km² land donation
+ 362 km² concession
E-ELT
VLT

The design

The E-ELT: overview

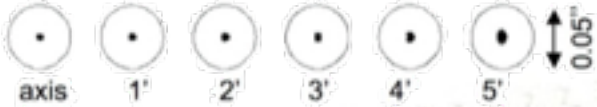


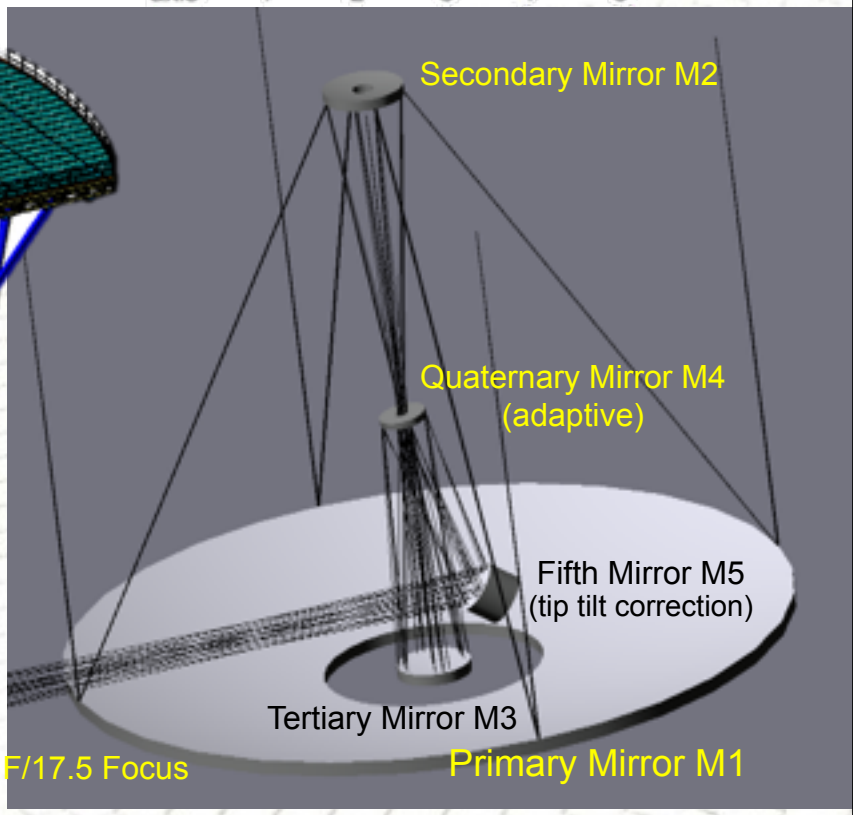
The E-ELT: overview



Optical design

- 3-mirror anastigmat on axis + 2 flats
- diffraction limited over full 10′ FoV
- Nasmyth, coudé foci
- very low LGS wavefront aberrations

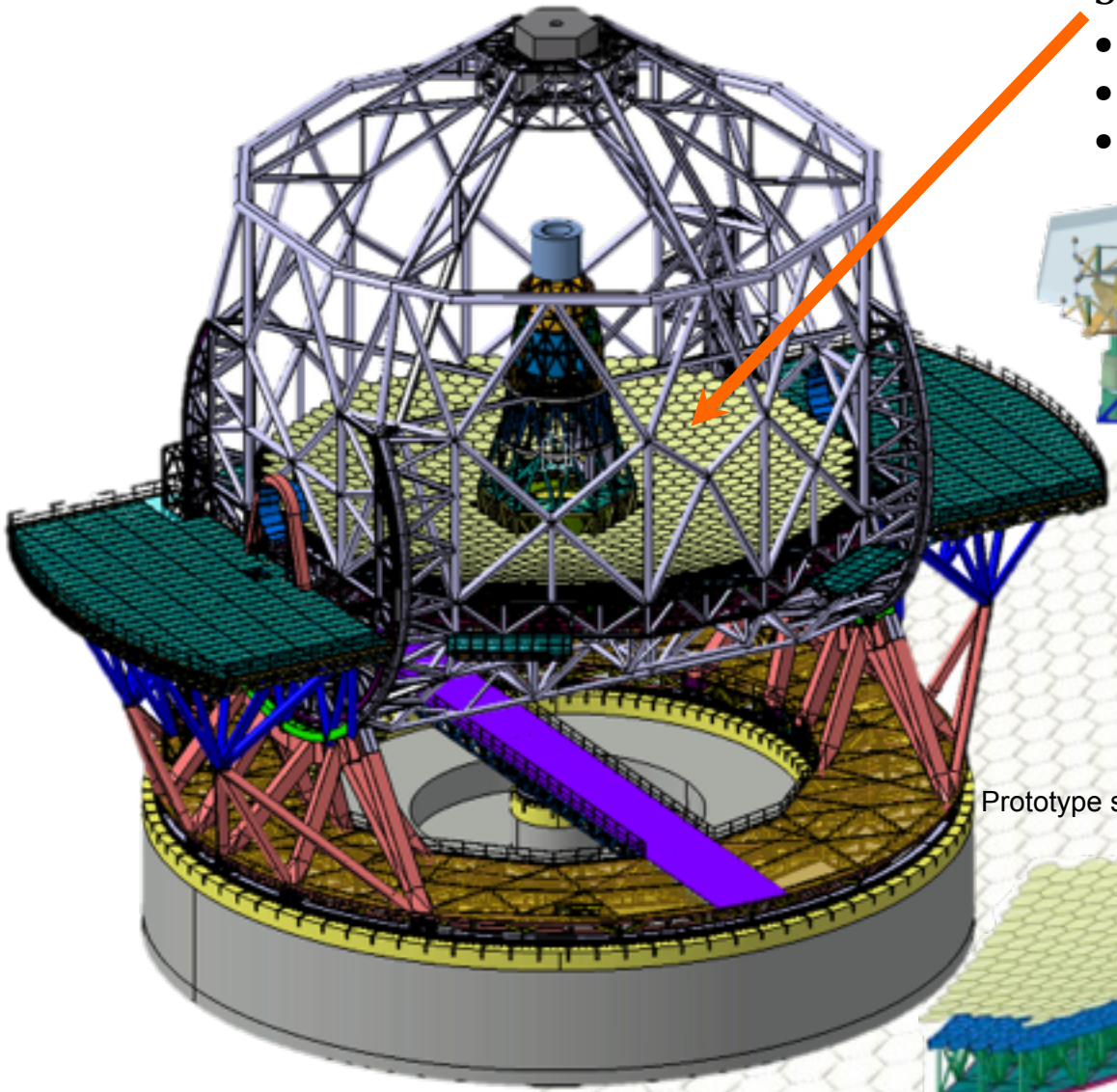


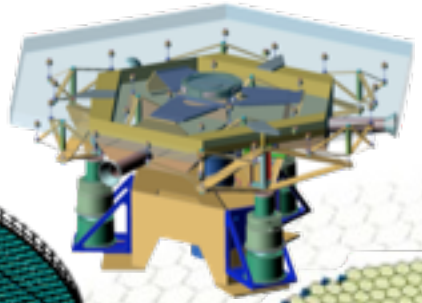


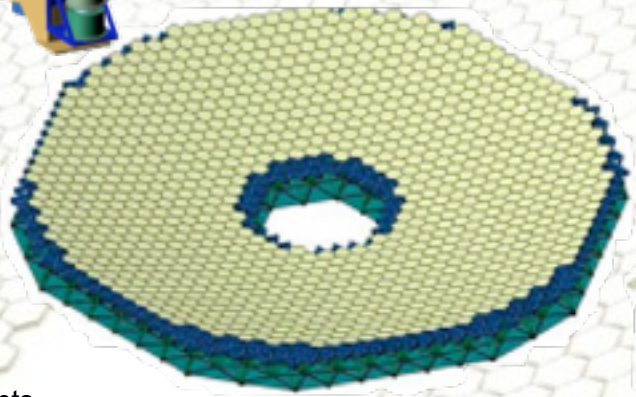
The E-ELT: overview

39m Primary Mirror

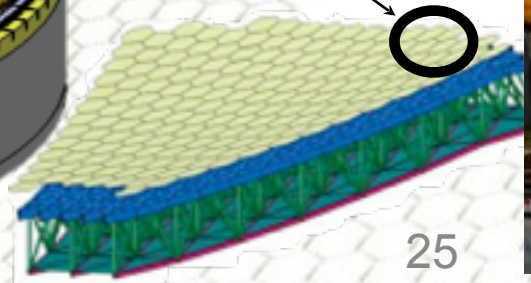
- 798 segments mirror +1/family
- 2 x 7 prototypes FEEDs
- prototype support, PACTs, edge sensors







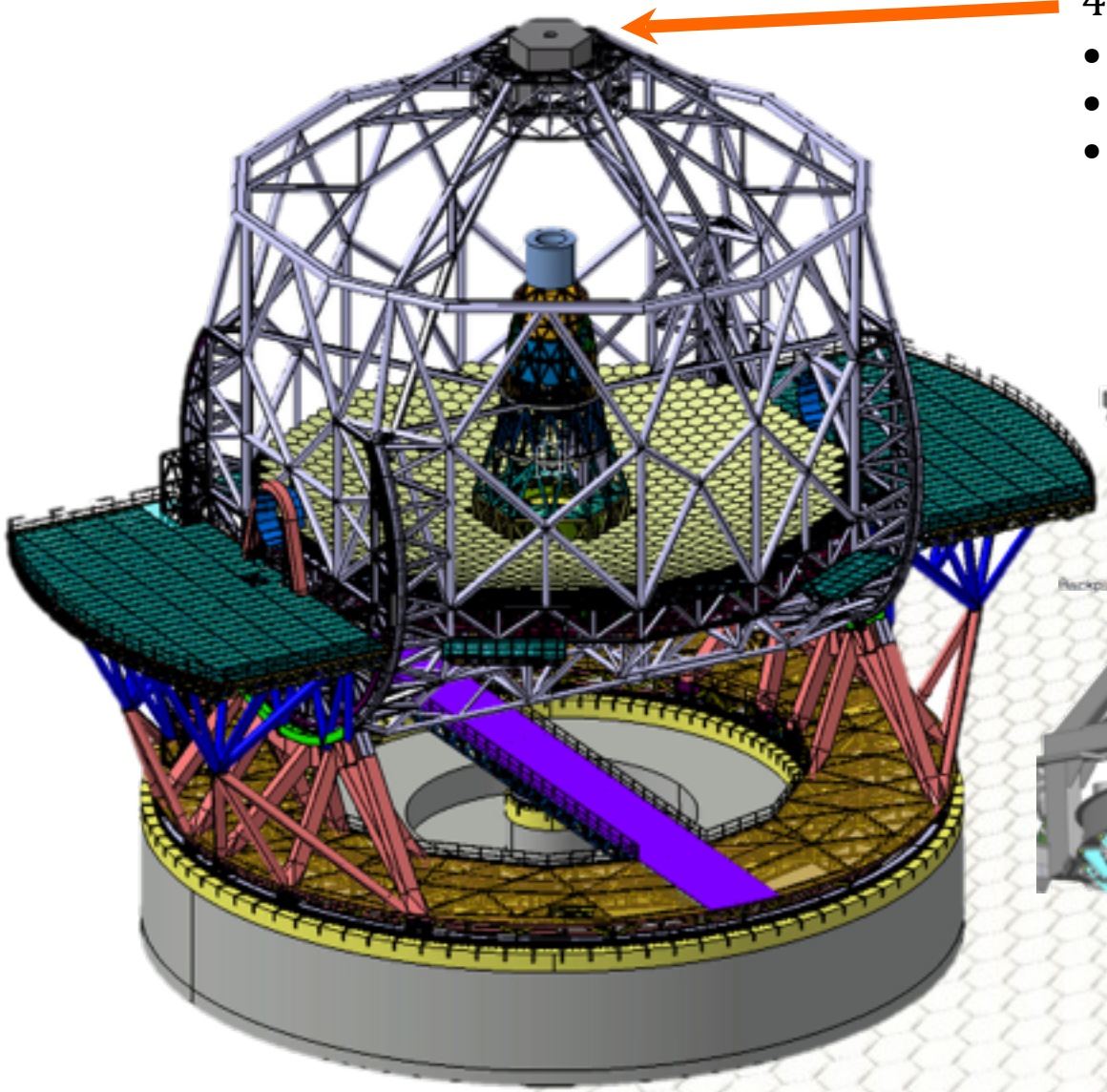
Prototype segments

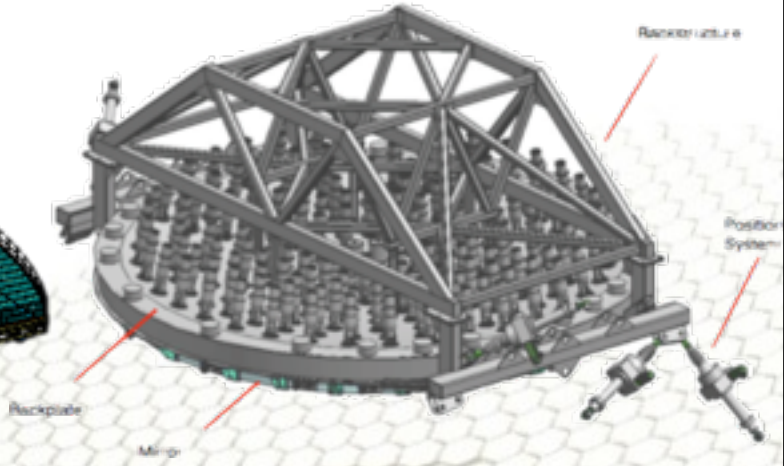


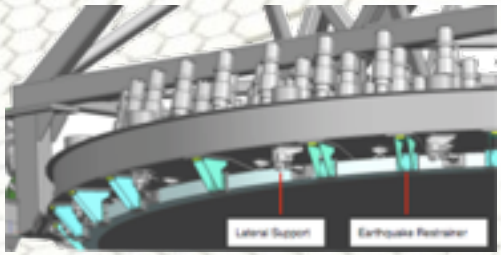
The E-ELT: overview

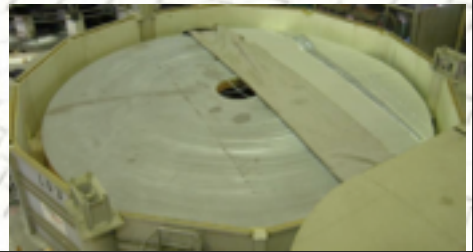
4m Secondary Mirror

- M2 unit FEED
- 3 polishing studies
- prototype actuators



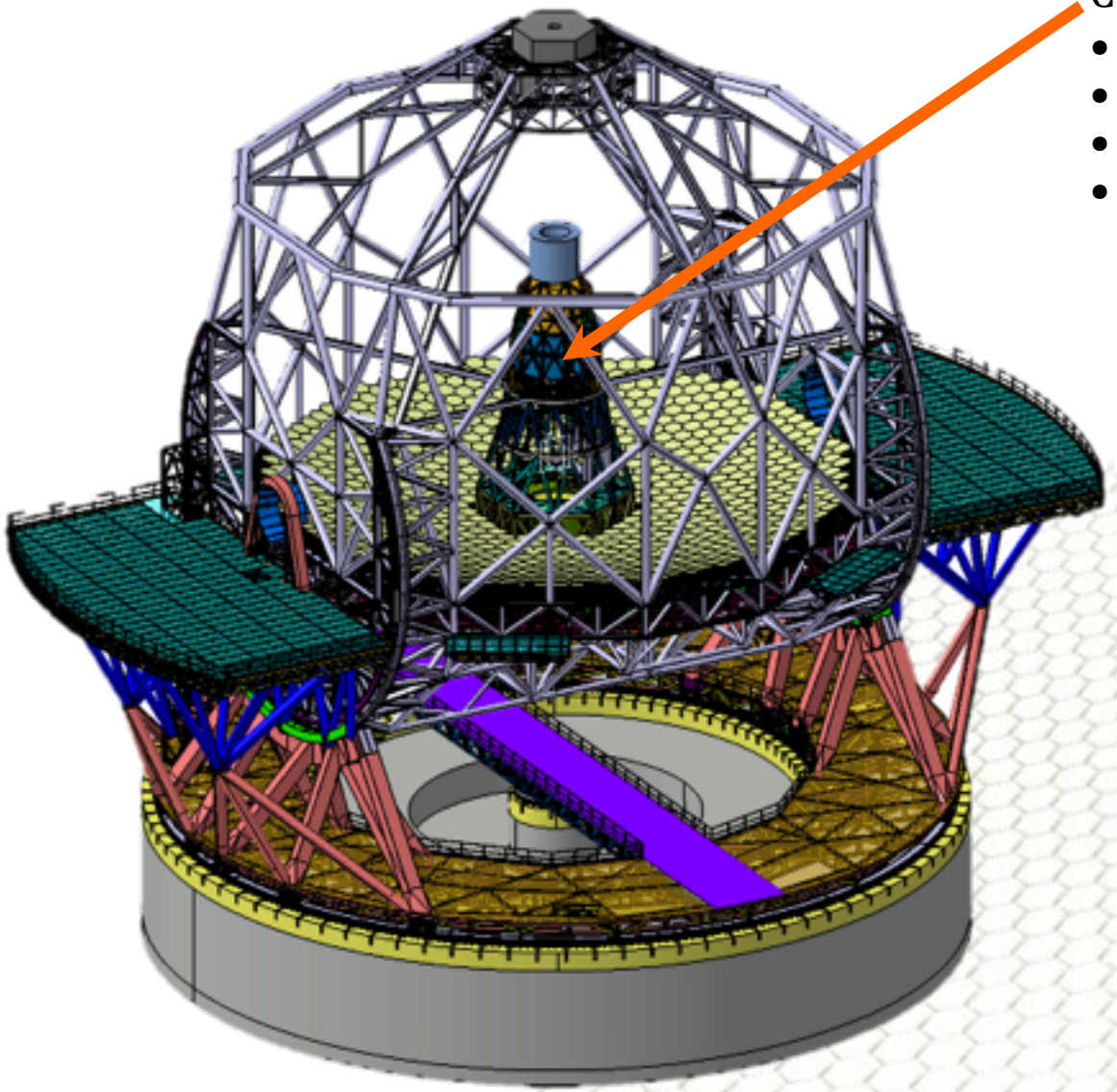


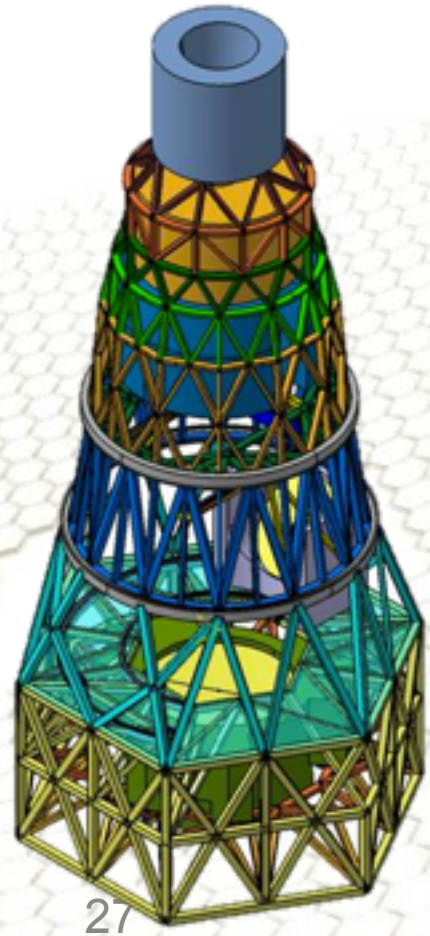




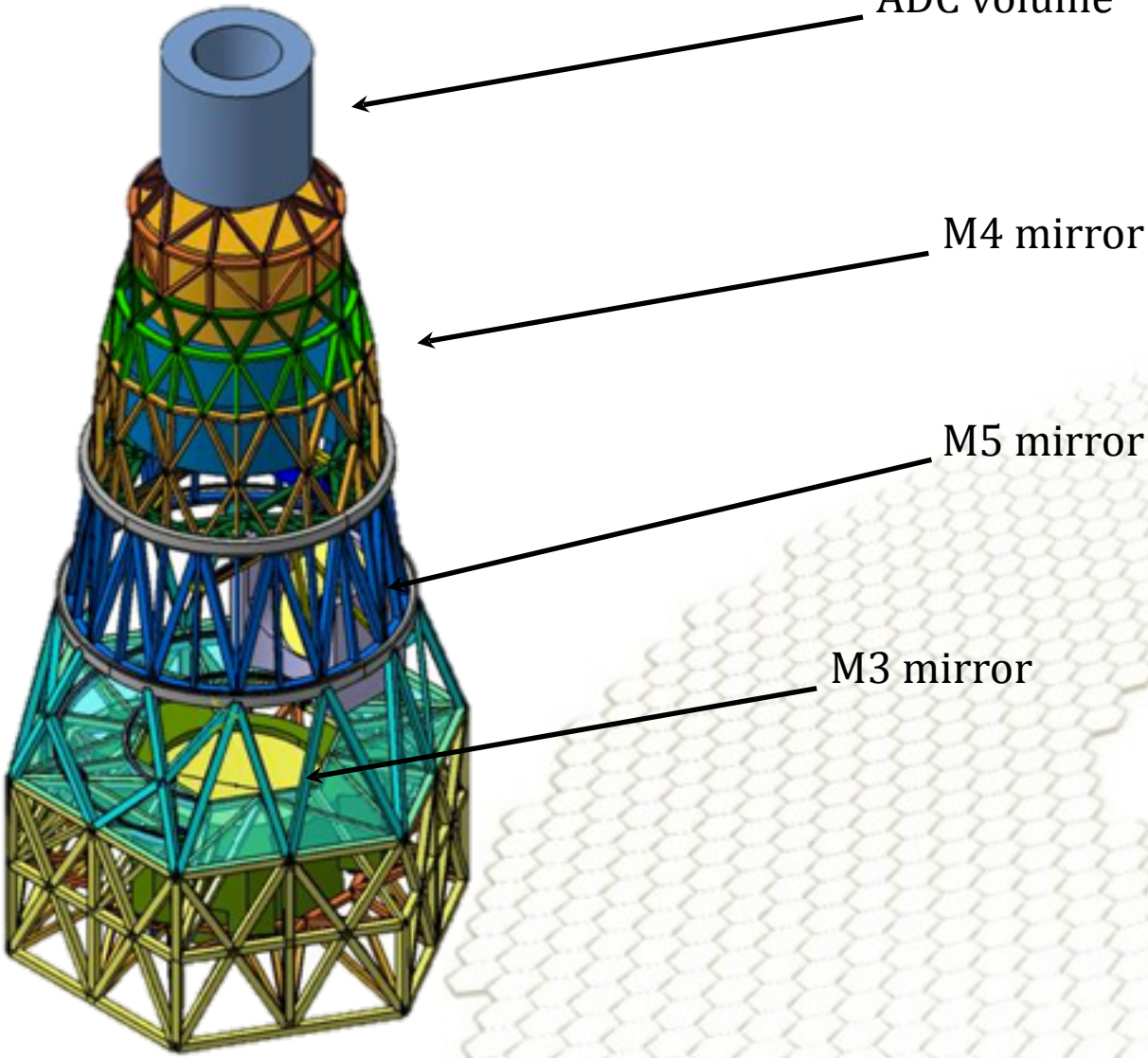
The E-ELT: overview

Central tower
- ADC volume
- Adaptive M4
- Field stabilization M5
- M3

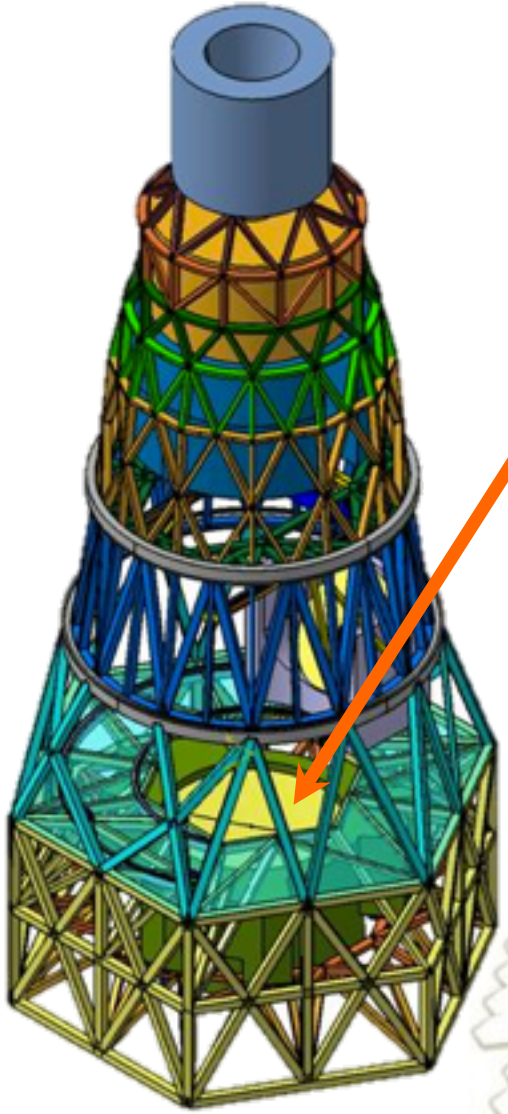




The E-ELT: overview

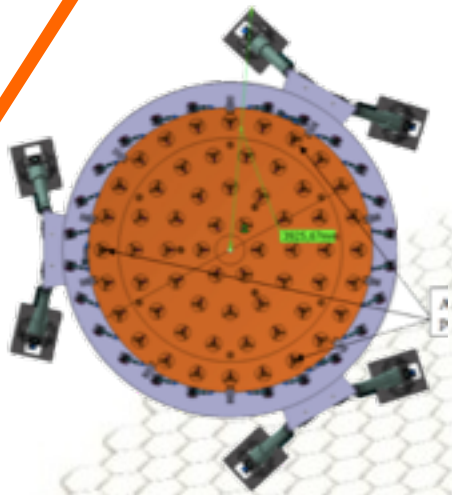


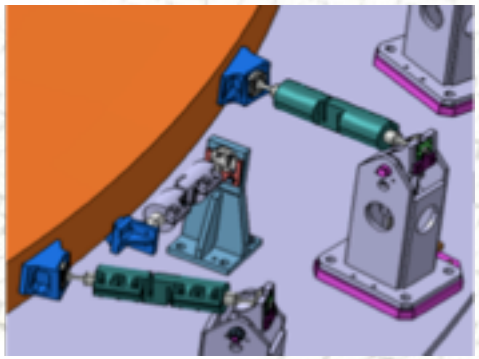
The E-ELT: overview

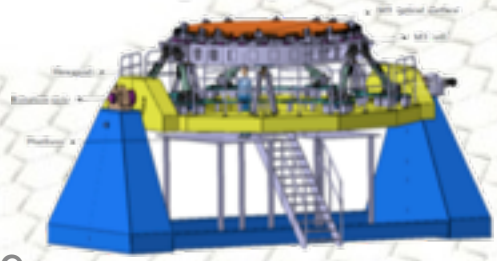


4.2m M3 unit

- Preliminary cell design concluded
- Prototype pneumatic actuators



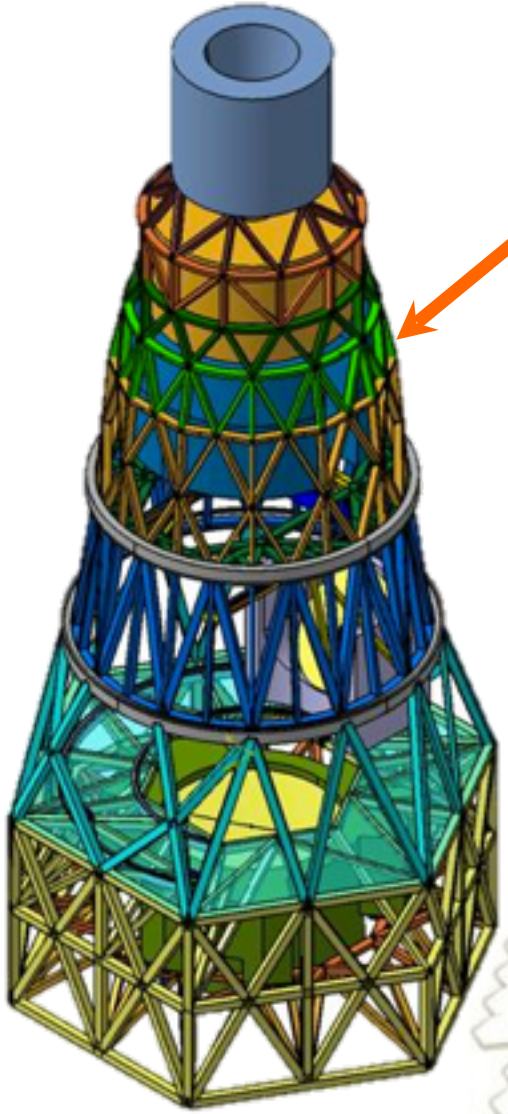


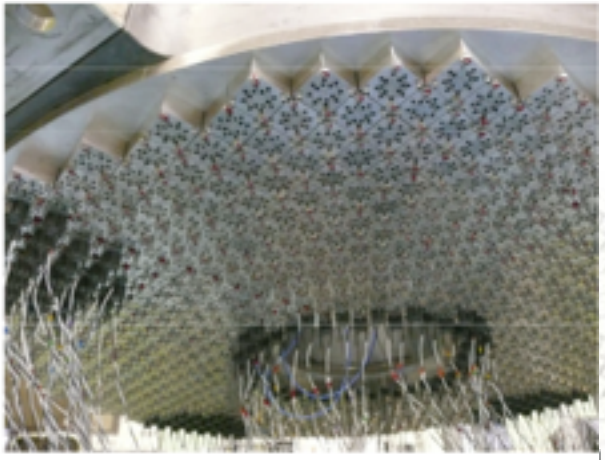


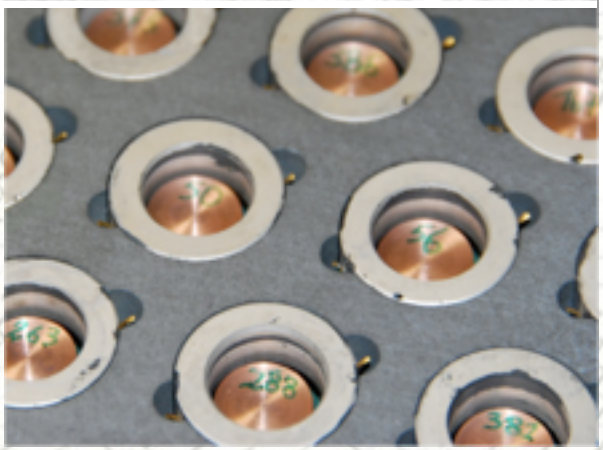
The E-ELT: overview

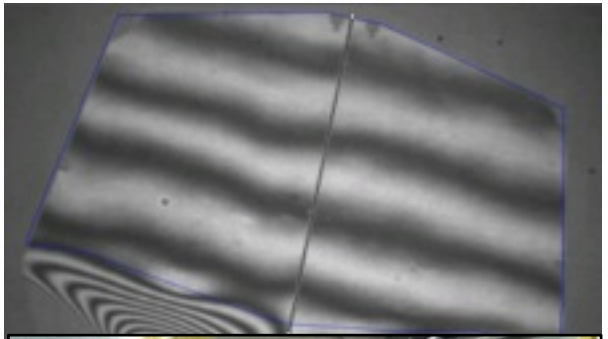
2.5m M4 unit

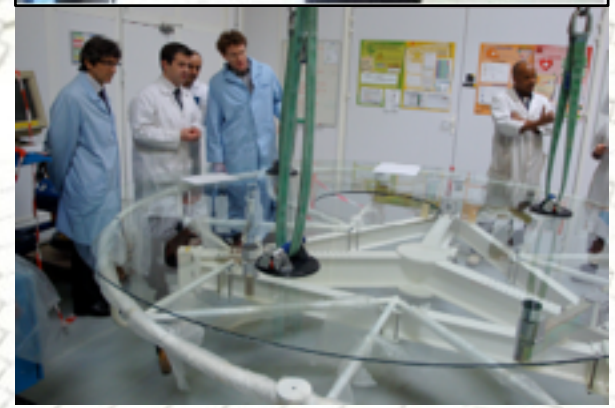
- 2 FEEDS (prototypes)
- Thin shells polishing
- **Construction contract ongoing**



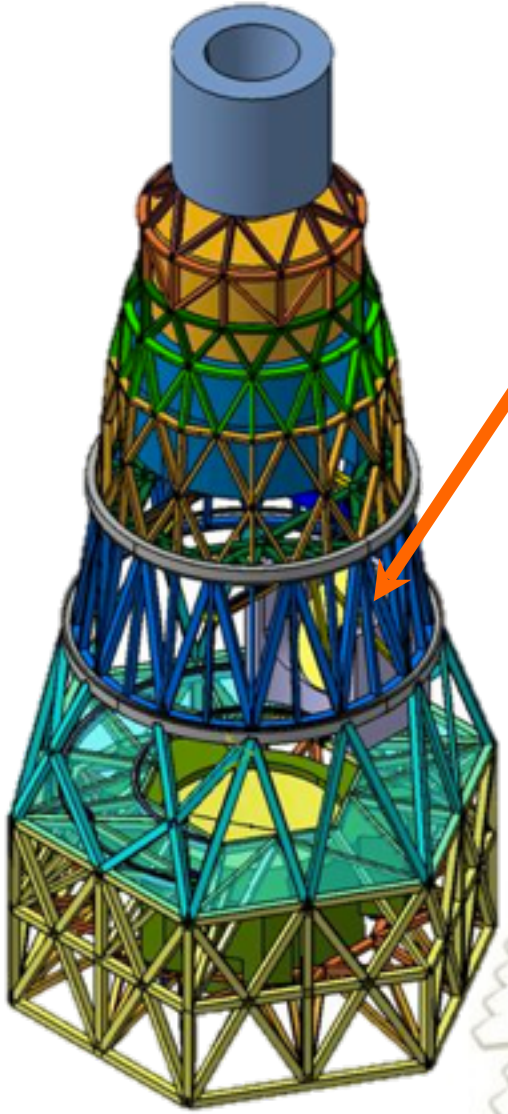






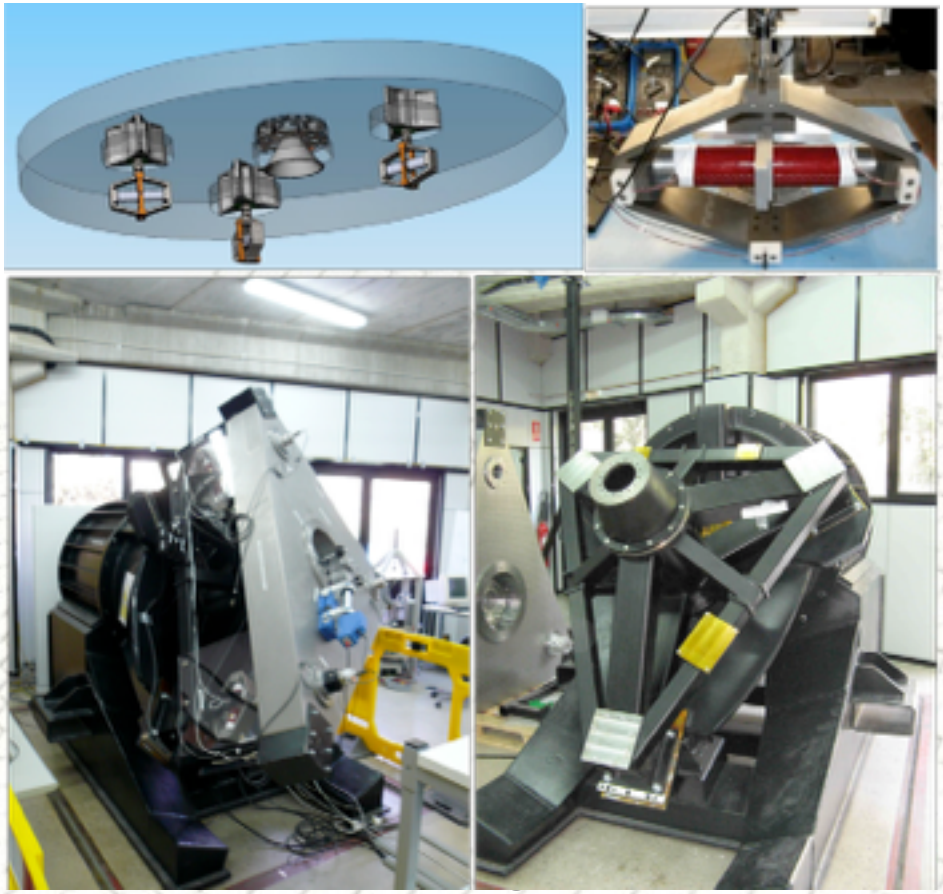


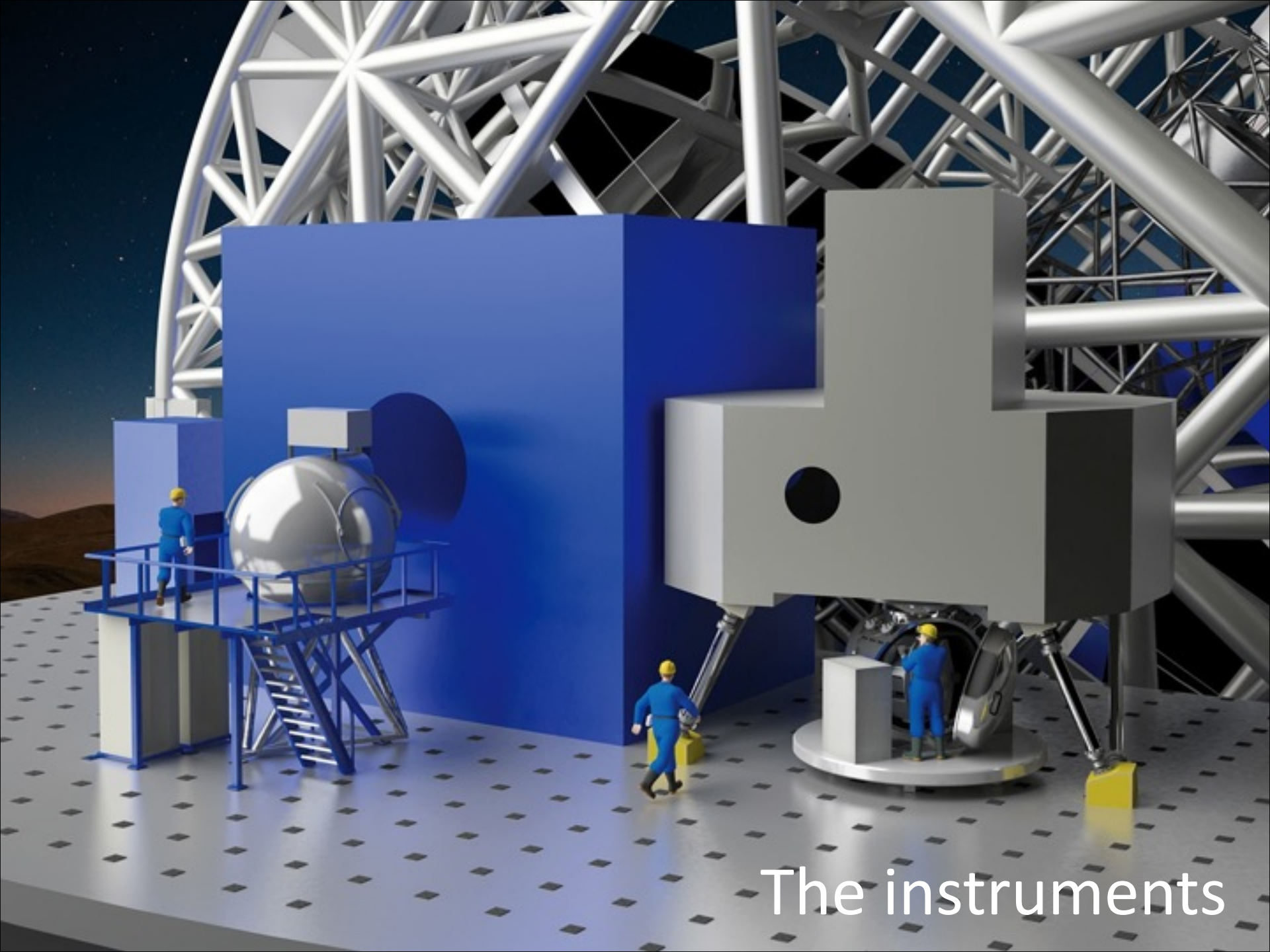
The E-ELT: overview



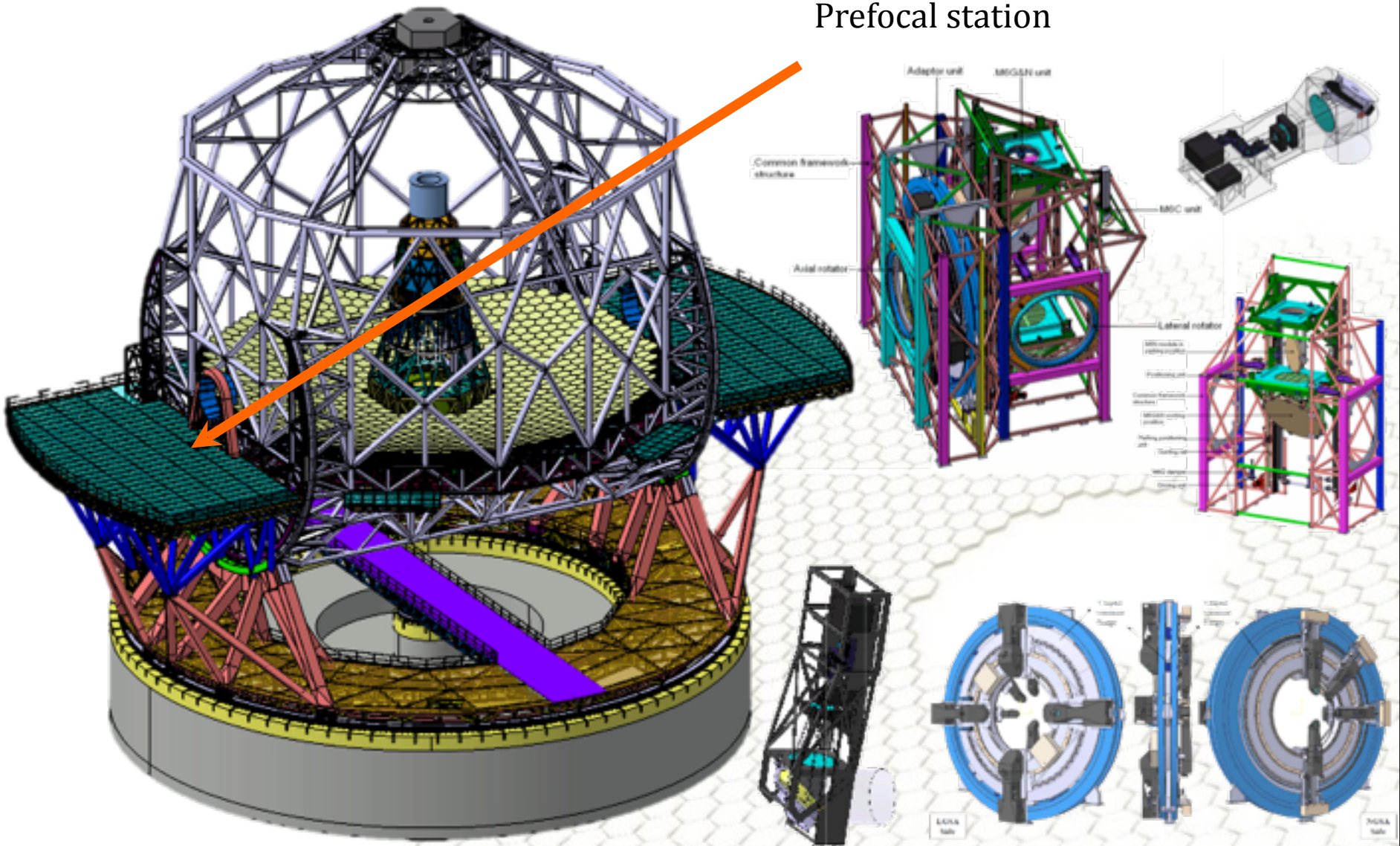
2.4m x 3m M5 unit

- scale-1 electromechanical prototype FEED
- 4 mirror polishing studies (including heavy option)




The instruments

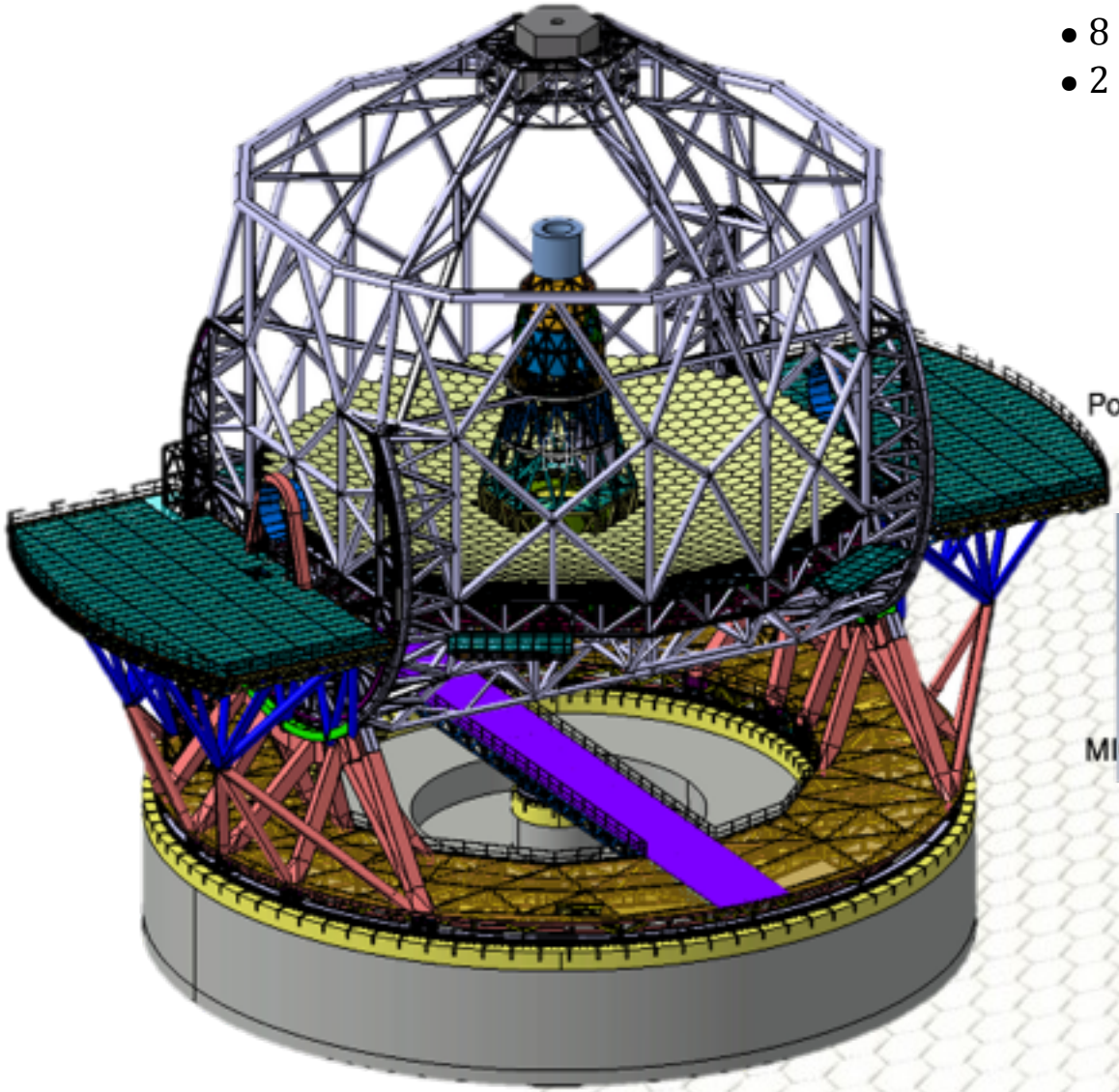
The E-ELT: overview



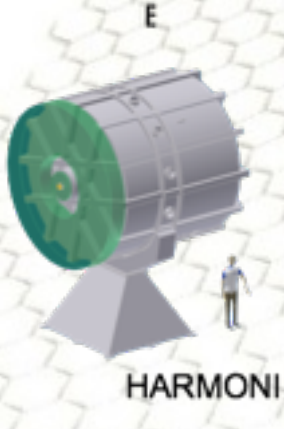
The E-ELT: overview

Instrumentation

- 8 instrument concepts Phase A concluded
- 2 post-focal AO modules Phase A concluded



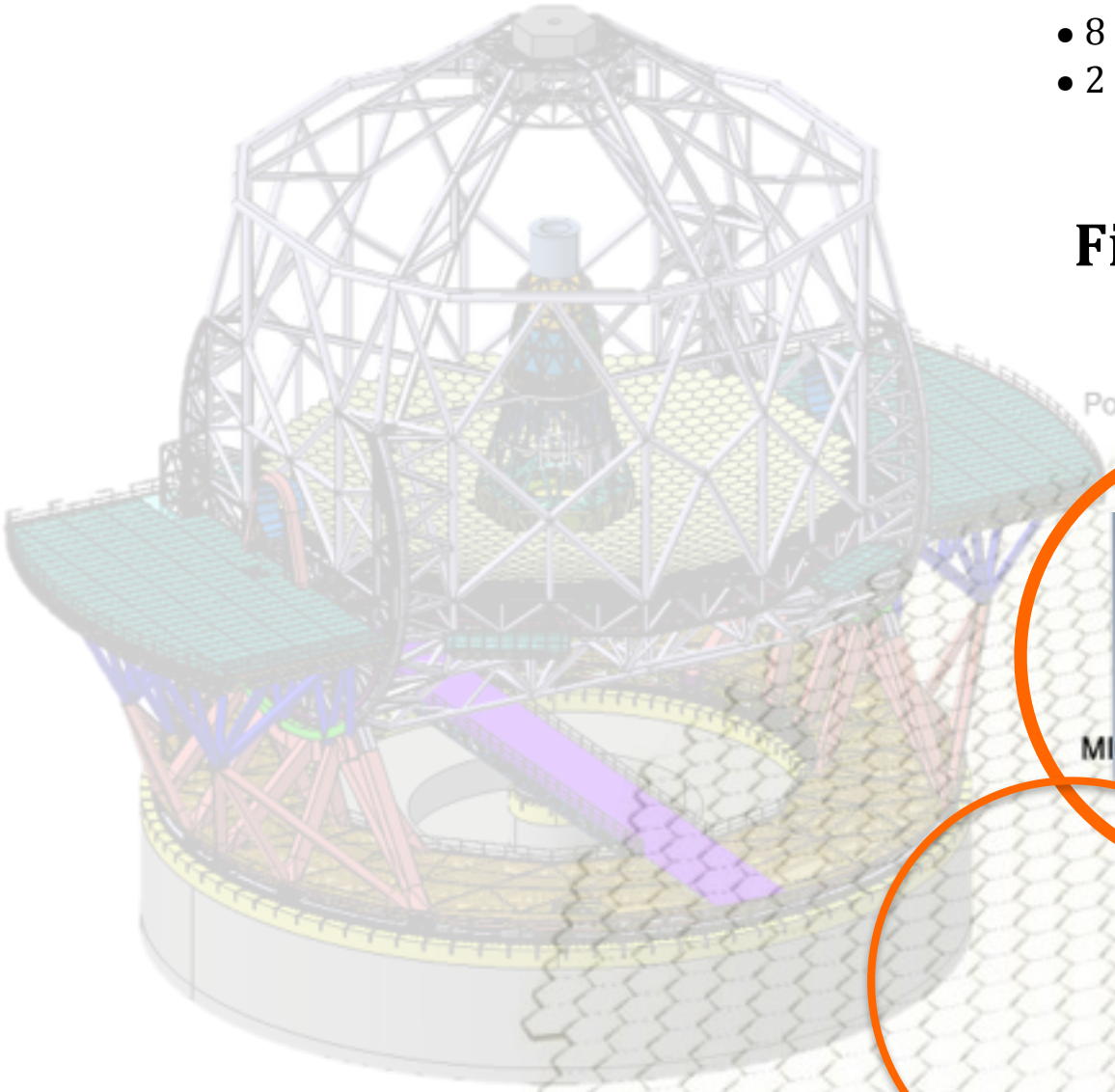
Possible instruments location



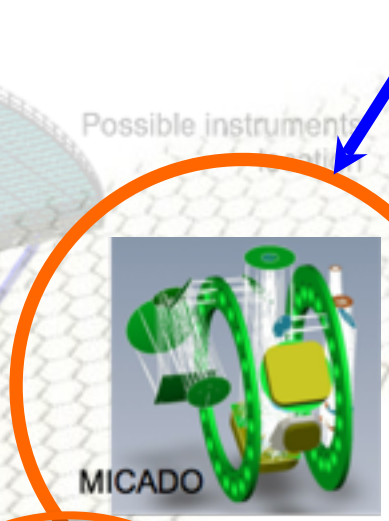
The E-ELT: overview

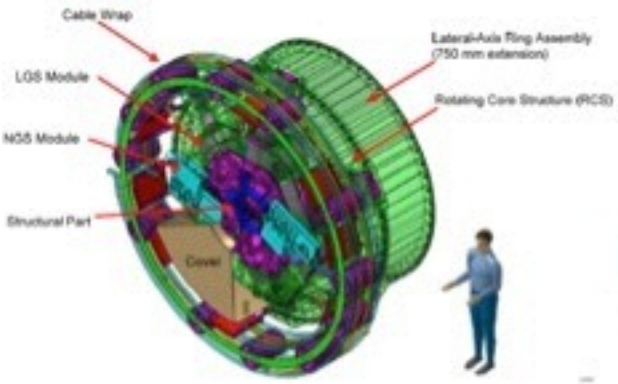
Instrumentation

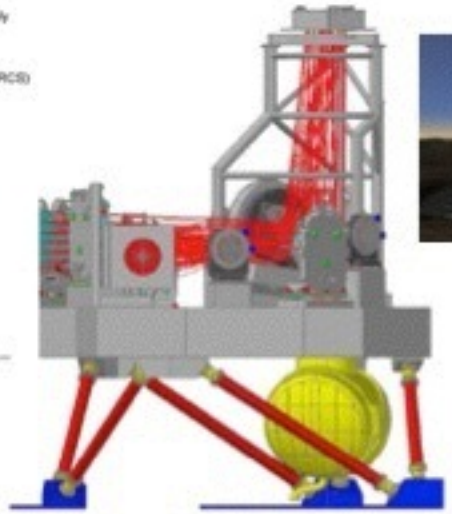
- 8 instrument concepts Phase A concluded
- 2 post-focal AO modules Phase A concluded

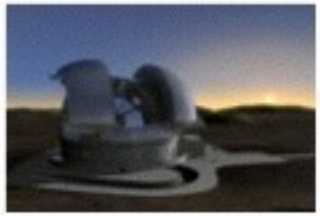


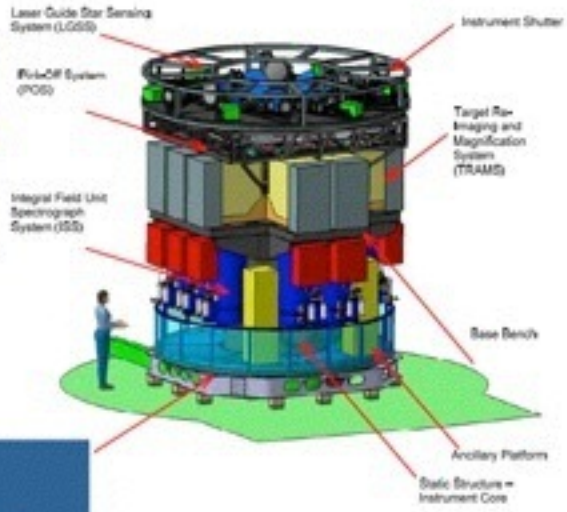
First Light Instruments

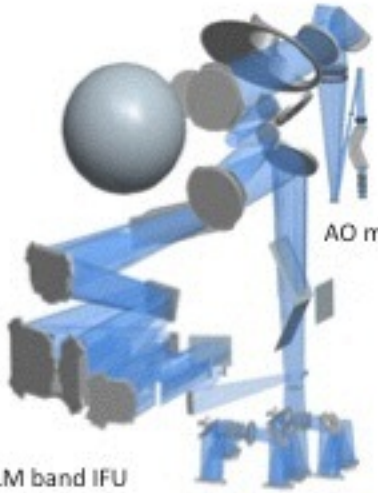






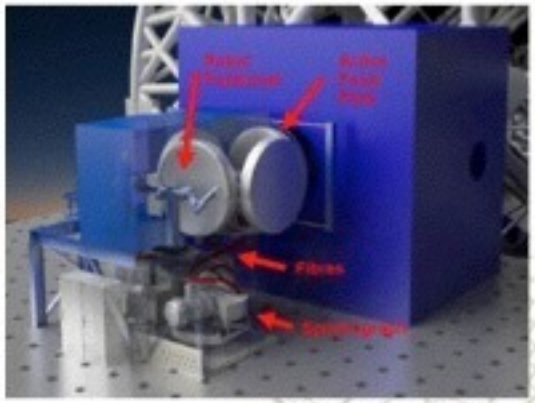




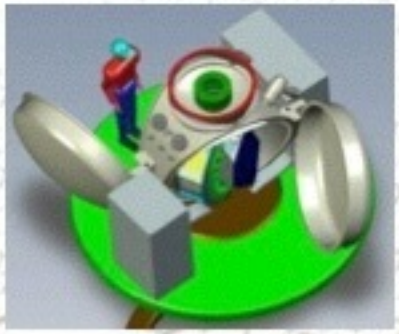


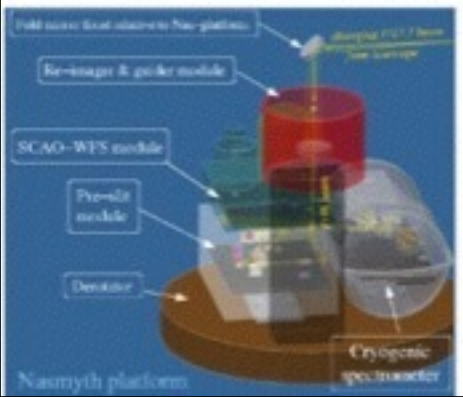
AO module

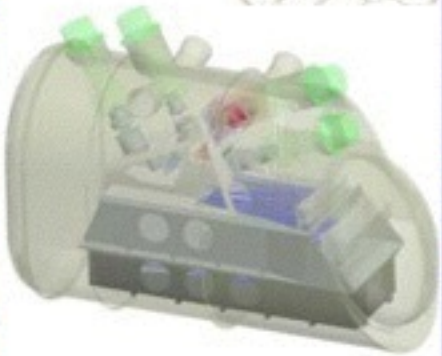
LM band IFU spectrograph

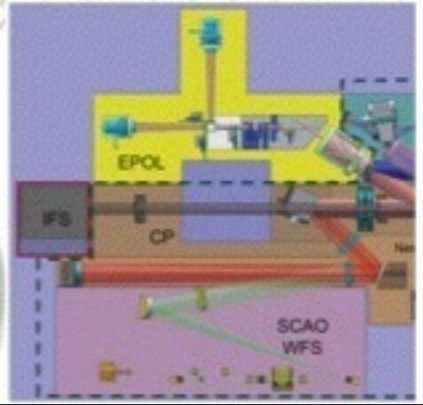


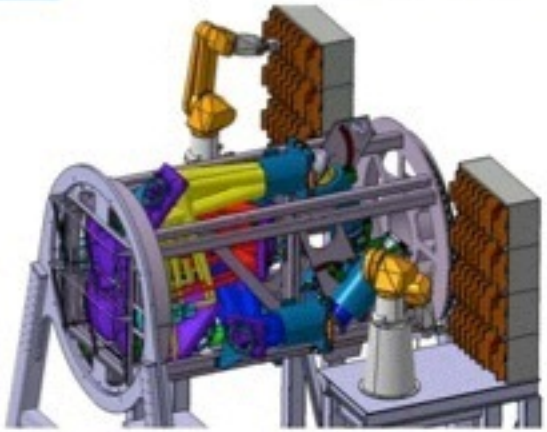
Imager (LM and N-band channels)











Roadmap (1): First light instruments

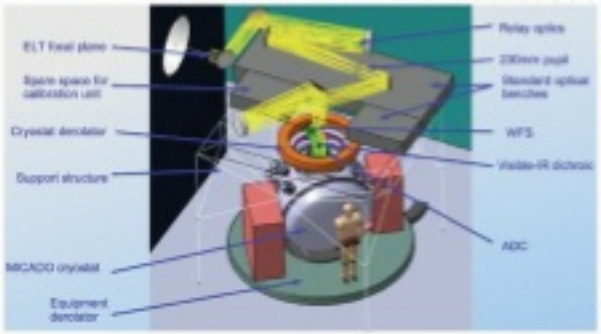
- Two first light instruments are ELT-CAM and ELT-IFU plus their AO systems
- ELT-CAM plus MAORY
- AO for ELT-IFU under study within the scope of the work on the pre-focal station
  - ATLAS study for an LTAO module at Phase A
- Both instruments are undergoing revisions to the Phase A concept to meet their Top Level Requirements

ELT-CAM/MICADO

Diffraction-limited NIR Camera

PI: Davies, post Phase A
MPE, MPIA, USM, INAF-OAPD, NOVA , LESIA
At ESO A. Richichi

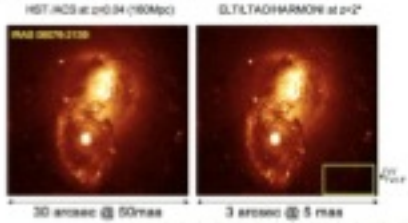
- 53" across, 3mas pix
- high throughput
- Moderate resolution long-slit spectroscopy



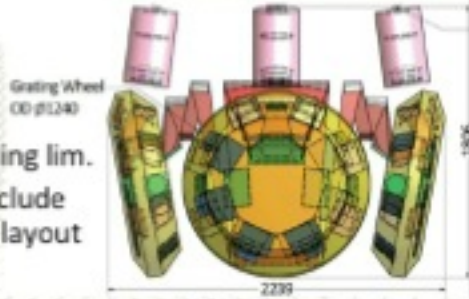
ELT-IFU/HARMONI

Single field, wide band IFU, NR spectrometer

PI: Niranjan Thatte,
Oxford, CRAL, CSIC, IAC,UK ATC, ONERA
At ESO J. Vernet



- Wavelength range
  - 0.47-2.45μm
- Spectral resolving power
  - R = 400, 4000, 10000, 20000
- 4 spatial scales
- 4 fields of view (diff. lim to seeing lim.
- Modifications since Phase A include considering a gravity invariant layout (shown)

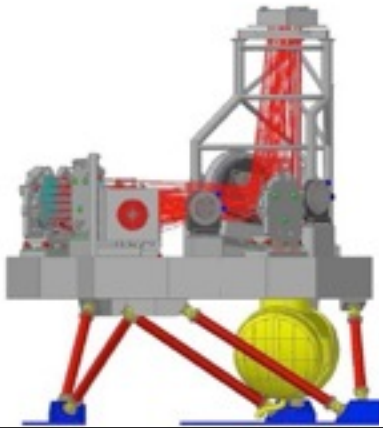


MAORY

Multi-conjugate AO

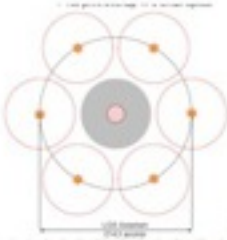
PI: Emiliano Diolaiti
INAF (Bologna, Padova, Arcetri), ONERA
At ESO: E. Marchetti

- Multi-conjugate AO
  - 6 laser, 3 natural guide stars
  - MAORY deformable mirrors conjugated to 4km, 12.7km
  - Two output ports
- Performance
  - 0.6 μm < λ < 2.4 μm
  - wide field - 2', 1' clear
- Instrument 'clients'
  - SIMPLE, MICADO

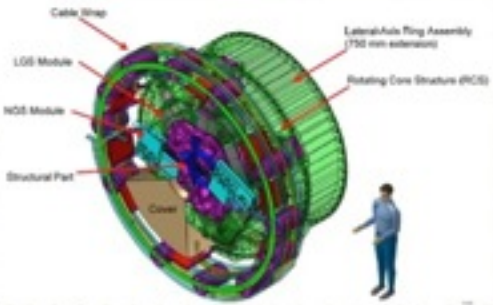


ATLAS: Laser Tomography AO

- PI: Thierry Fusco
- ONERA,GEPI, LESIA, UK ATC, LAM
- At ESO: J. Paufique



- Concept
  - Uses the telescope adaptive mirrors
  - No additional mirrors in the instrument optical path
  - 6 LGS, 2 NGS
- Performance
  - 52% strehl in K band
  - With 92% sky coverage
  - 30' field of view
- Instrument 'clients'
  - SIMPLE, HARMONI, METIS



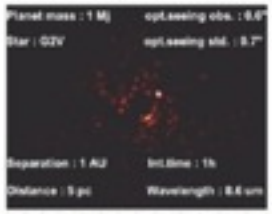
Roadmap (2): ELT-3,4,5 and ELT-PCS

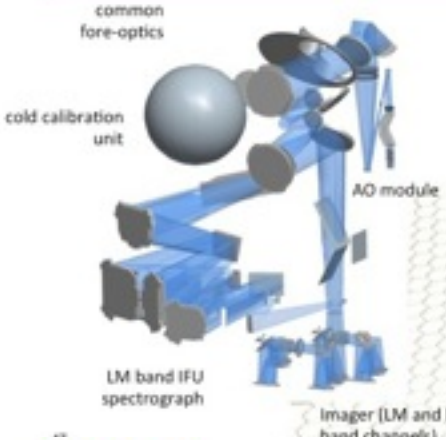
- ELT-MIR, ELT-HIRES and ELT-MOS are all selected
  - ➢ ELT-MIR will be based on METIS
  - ➢ ELT-MOS and ELT-HIRES will be the subjects of a new call for ideas
- ELT-PCS will start once the technology reaches maturity

ELT-3/METIS

Mid-infrared ELT Imager and Spectrograph

PI: Bernhard Brandl,
Nova, MPIA, CEA Saclay, KU Leuven, UKATC
At ESO R. Siebenmorgen



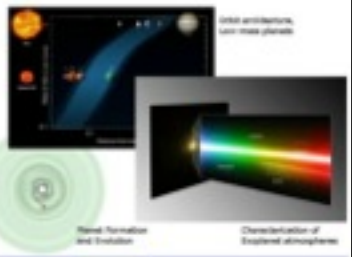


- Diffraction limited imager [18"×18"]
- L/M band and N band
  - includes coronagraphy
  - R ≤ 5000 long-slit spectrometer
  - includes polarimetry
- High resolution IFU (≥ 0.4"×1.5" fov) spectrograph for L/M, (R ~ 100,000)
- LTAO/ATLAS plus on-board SCAO

EPICS

exo-planet imaging camera and spectrograph

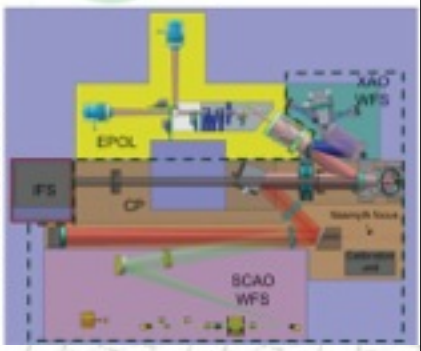
- PI: Markus Kasper, ESO
- LAOG,LESIA, Uni. Nice, LAM,ONERA, Uni.Oxford, INAF, ETH Zurich, NOVA



IFS 0.95-1.65µm
FOV: 0.8" x 0.8"/2.33mas
0.8" x 0.014" long slit
R = 125, 1400 and 20000

EPOL 0.6-0.9µm
Coronagraphic polarimeter
FOV: 2" x 2"/1.5mas

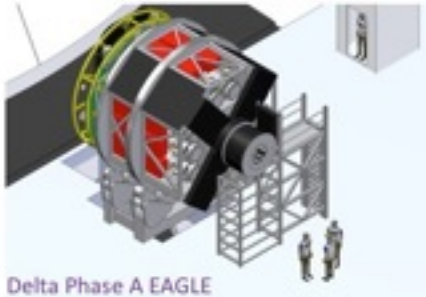
Contrast ratios – 10^{-8} – 10^{-9}
XAO – very high (90%) Strehl



ELT-MOS

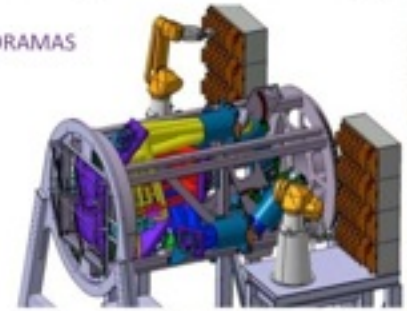
Instrument Top Level Reqs

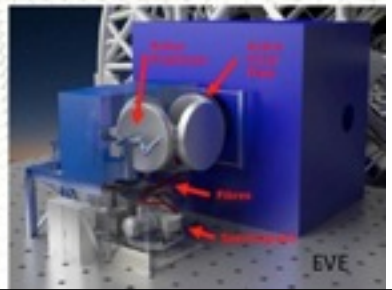
- 0.4-2.45um wavelength range
- 1 000 < R< 15 000
- Multiplex ~>400 and 2-100 (with AO)
- Seeing limited or MOAO-type



Delta Phase A EAGLE

DIORAMAS

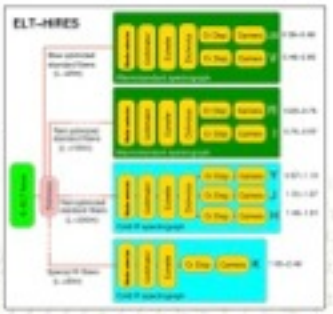


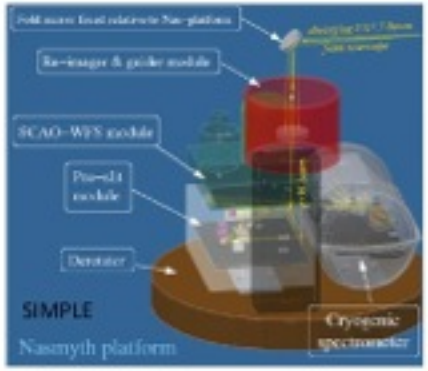


ELT-HIRES

Instrument Top Level Reqs

- 0.37-2.5um wavelength range
- 100 000 < R< 200 000
- Diffraction limited resolution >1um
- Also seeing limited performance





The eMIDIR science case

- Proto-planetary disks and the formation of planets
- Characterization of exoplanets
- Physical characterization of the transition from brown dwarfs (L,T, Y-type) to giant planets
- The formation history of the solar system
- Dust formation in the transition from thermal pulsing AGB to OH-IR to PNs (LMC, SMC)
- Extragalactic transients
- Active Galactic Nuclei and the Growth of Supermassive Black Holes

eMIDIR requirements

	Field of view	Spectral coverage	Spectral resolution	IFU	AO	coronography	polarimetry
Proto-planetary disks		3- 13 μm	100,000	yes	Diffr/lim	yes	
Exoplanets		L, M & N	500 in imaging 100,000 spec		Diffr/lim	Yes/ADI	
Formation of solar system		L, M & N (goal Q)	1,000 100,000		With differenti al tracking		
AGB	Few tens of arcsec	L, M & N	70,000 L & M 40,000 N		High strehl	Yes (tbd)	Yes (tbd)
Transients	At least 20 "	L, M, N & Q	Few 1,000		< 0.1"		
SMBH	>= 0.5"	L, M & N	3,000 – 5,000		Diffr limit		

Roadmap Feb 2014

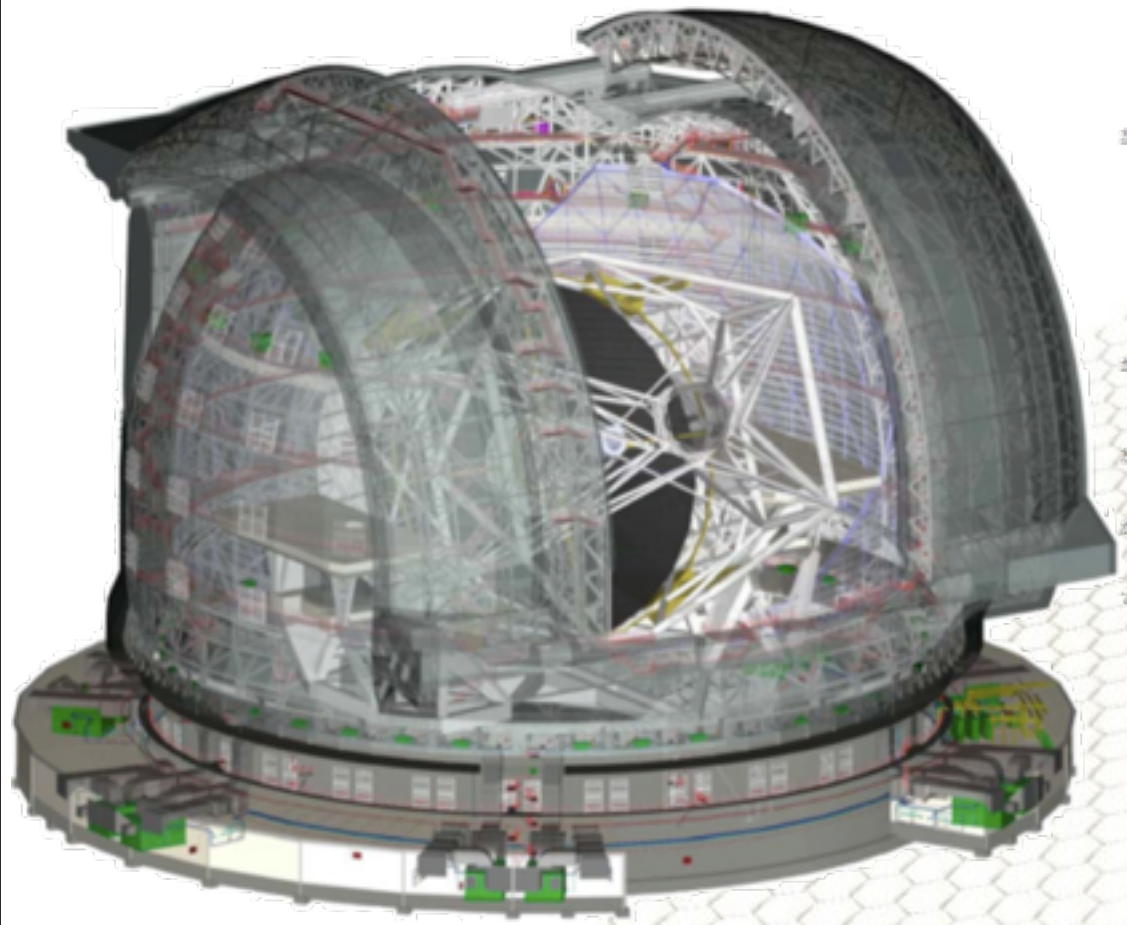
Year	ELT-IFU + LTAO	ELT-CAM + MCAO	ELT-MIR	ELT-MOS	ELT-HIRES	ELT-6	ELT-PCS
2012	Develop science reqmts, AO architecture.						
2013			Develop science requirements for MIR/MOS/HIRES				
2014			VISIR start on-sky. Detector check.	Call for proposals Start Ph A	Call for proposals Start Ph A		Start ETD
2015				Consortium selection for construction	Consortium selection for construction		
2016						Call for Proposals	
2017						Start Ph A	TRL check – start when ready
2018							
2019						Consortium selection for construction	
2020							
2021							
2022							
2023							

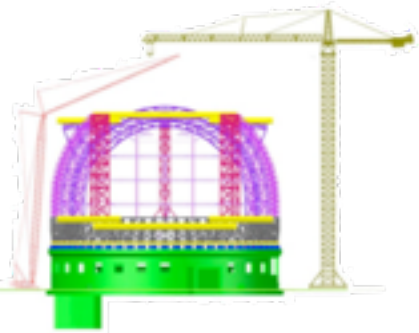
	Pre-studies taking the form of Phase-A or delta-Phase-A work and/or ESO-funded enabling technology development (ETD)
	Decision point
	Development of Technical Specifications , Statement of Work, Agreement, Instrument Start.

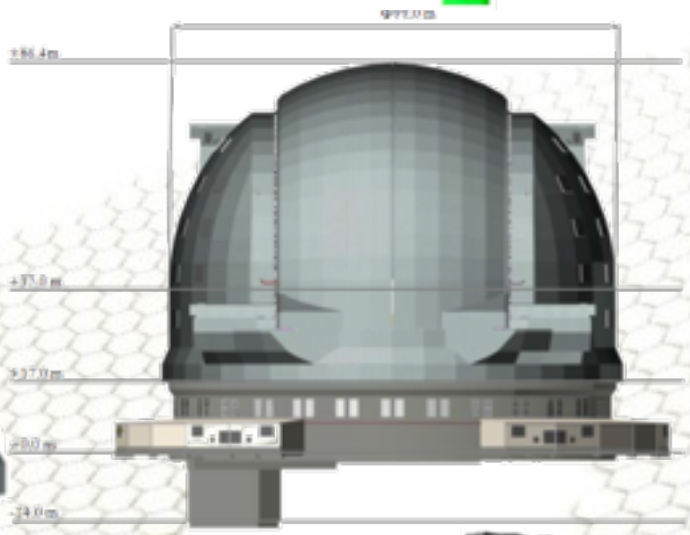
The E-ELT: overview

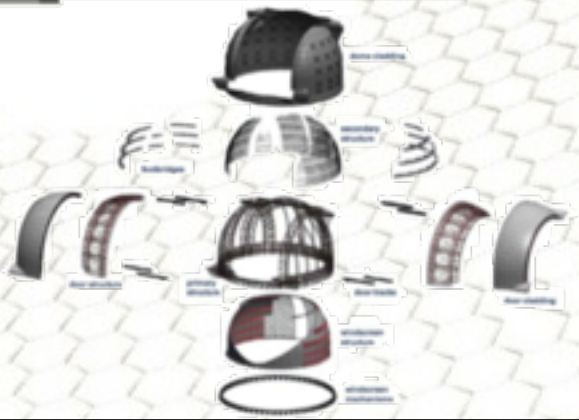
Dome

- 2 FEED contracts
- Erection sequence

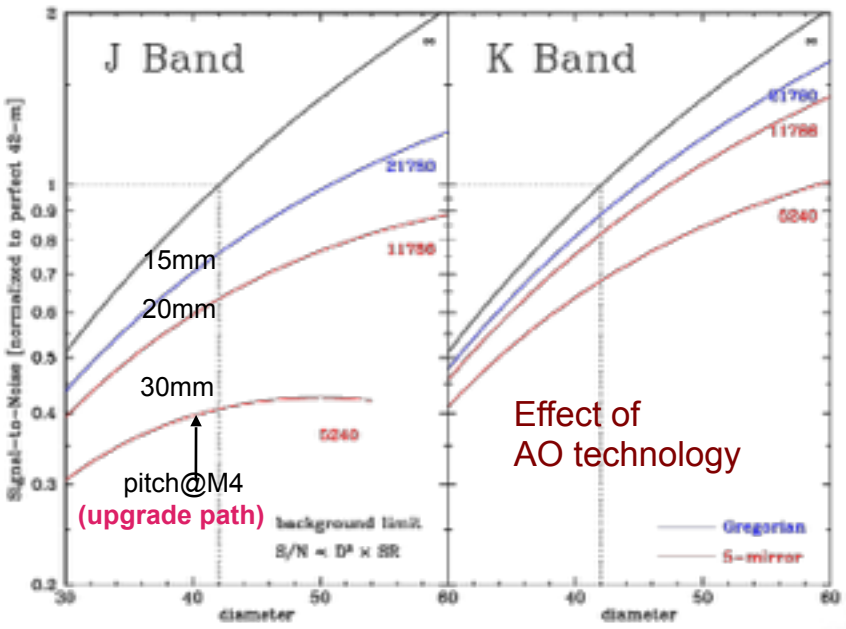


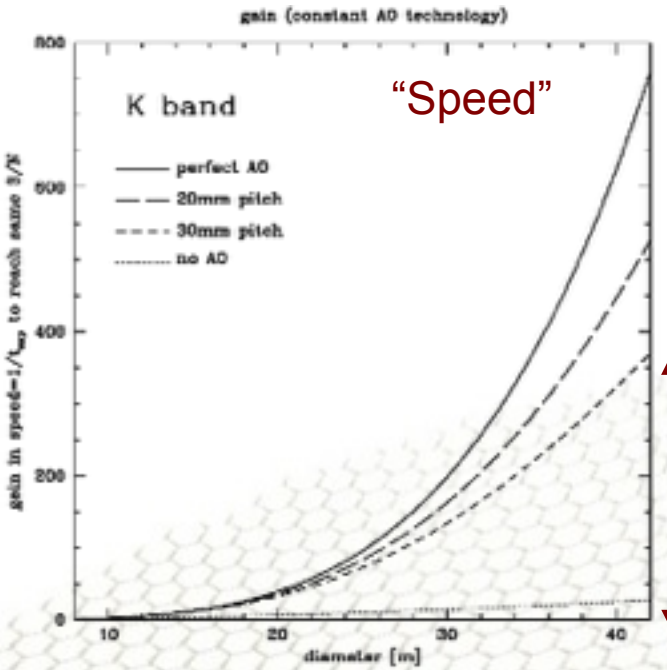






Summary: Powerful performance





λ/D:
3.5 mas @V
15 mas @K
30 mas @M

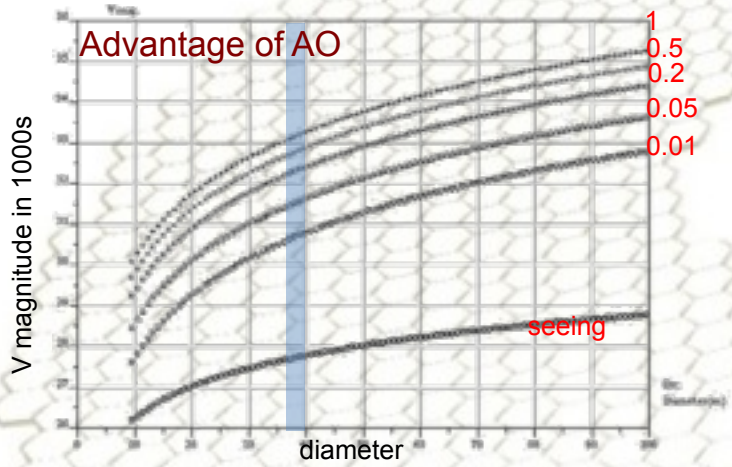
≈ 1 year
of VLT obs
in 1 night

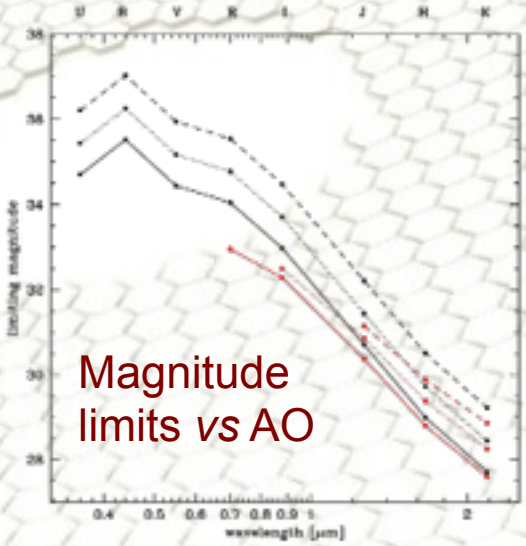
$S/N = F / \sqrt{(F+B+\ldots)}$

Flux: $F \approx F_0 \cdot SR \propto D^2 \cdot SR$
Bgd: $B = sky \cdot pix^2 \propto D^2 \cdot D^{-2} \equiv B_0$

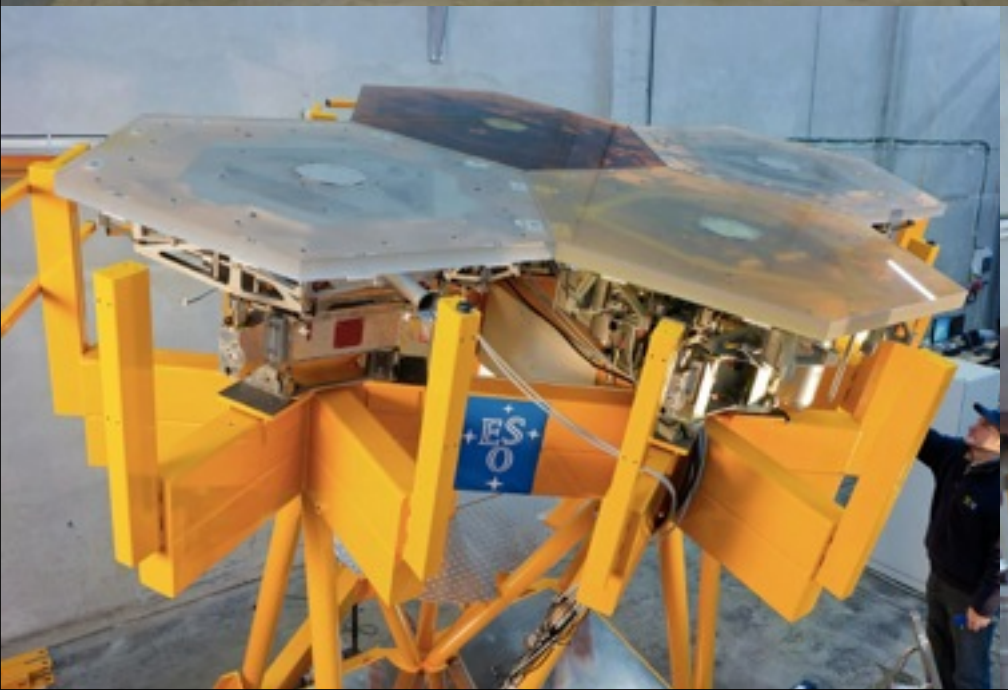
For faint sources:
$S/N \approx F/\sqrt{B} \propto \mathbf{D^2 \cdot SR}$

For exo-planets:
$S/N \approx F/\sqrt{B_\star} \propto \mathbf{D^2 \cdot SR^2/(1-SR)}$

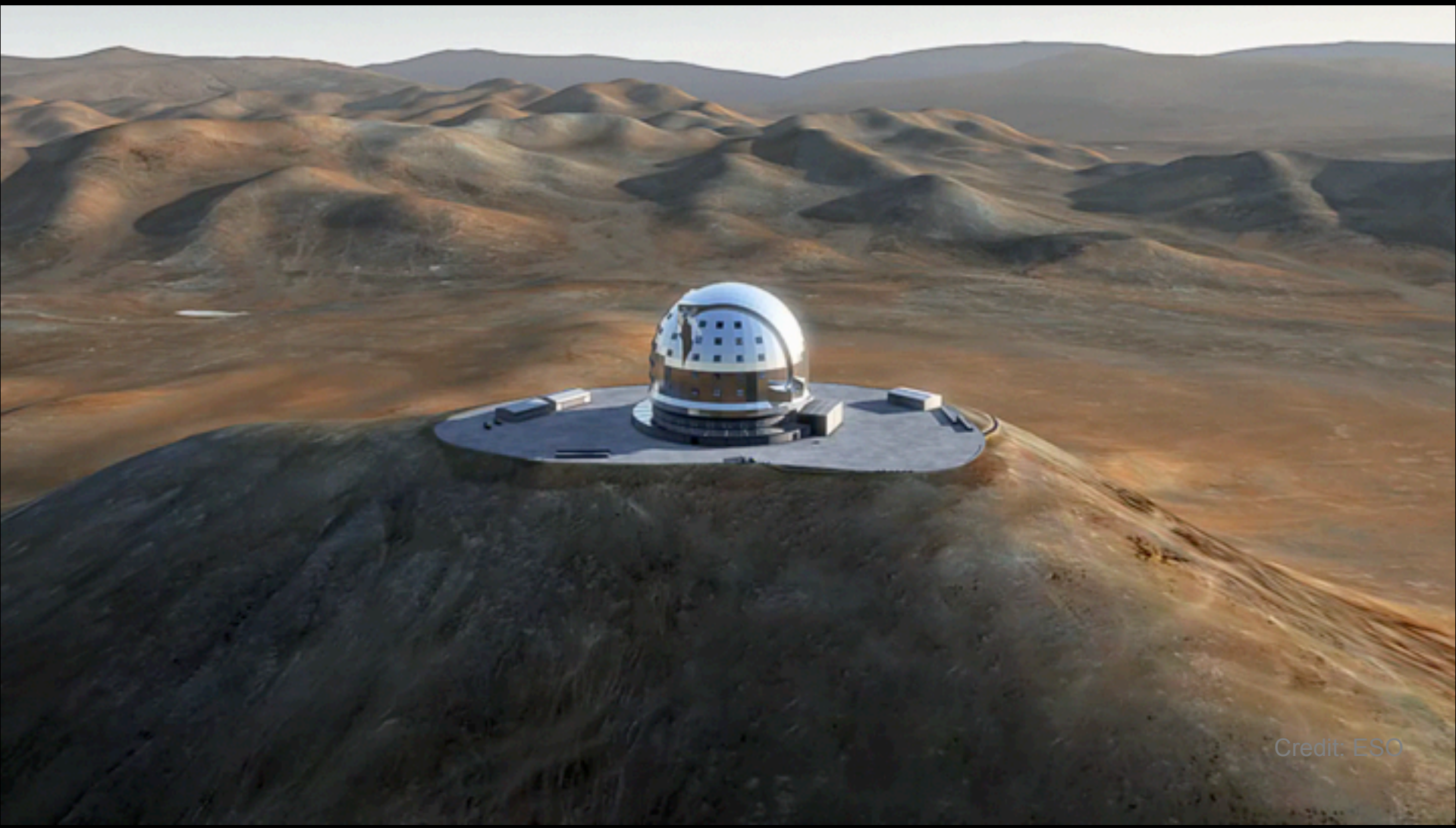




Current activities



Conclusions:
First light possible in 2023



Thank you